Project Number: MQP-GCC
LEC - AASC

GATEWAY CAMPUS CENTER

A Major Qualifying Project

Submitted to the Faculty

of the

WORCESTER POLYTECHNIC INSTITUTE
in partial fulfillment of the requirements for the
Degrees of Bachelor of Science in Architectural Engineering
and Bachelor of Science in Civil Engineering

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Abstract

This project presents the design of a Campus Center for Gateway Park. The team developed architectural, structural, mechanical, and fire-protection plans that met building code and provided a cost-efficient solution, fitting the requirements of WPI's Master Plan. The team focused on understanding how a building is designed while exploring the relationship between architecture and the engineering components of design.

Authorship

All members contributed evenly to the completion of this Major Qualifying Project and Report. All members co-edited the Project Report.

Zachary Harmony

Zachary was responsible for the Mechanical aspects of the project and assisted in architectural design. He wrote the following portions of this report:

- Envelope energy code compliance
- Effect of envelope on HVAC
- HVAC design
- HVAC problems and solutions (in the Tower section)
- How the project furthers WPI commitment to LEED certification and President Leshin's vision

Erin Murphy

Erin was responsible for the Architectural aspects of the project and assisted in structural design. She wrote the following portions of this report:

- Project motivation and design concept
- Architectural program and design
- Architectural and structural design of the Tower
- Tower functions and representation
- LEED analysis

Jillian Proulx

Jillian was responsible for the Architectural and Fire Protection aspects of the project. She also assisted in structural design. She wrote the following portions of this report:

- Introduction
- Site, building orientation on the lot, and zoning considerations.
- Architectural program, space requirements, adjacencies, construction type/height and area limits, and envelope design considerations
- Fire Safety Design section
- Why this project and report are important, and how the project meets the stated goals within the Implications and Analysis section.

Jeremy Soderholm

Jeremy was responsible for the Structural aspects of the project. He also assisted in architectural design. He wrote the following portions of this report:

- Site geotechnical considerations
- Tower structural problems and solutions
- Structural Design
- Integration of multiple disciplines and design tools developed
- Lessons for the future areas in the Implications and Analysis section

Acknowledgments

In completing our Major Qualifying Project, we were advised by many who deserve recognition. In order to meet the needs of both students and faculty, members of the WPI community were interviewed to discuss project goals and expectations. Additionally, members of WPI's Board of Trustees supported the goals of this project and allowed for open communication in the early planning stages of the project.

We would especially like to thank our advisors, Professsors Leonard Albano, Leffi Cewe-Malloy, and Kenneth Elovitz for their support and guidance through the MQP process. Additionally, Professor Milosh Puchovsky advised aspects of the fire protection and egress designs throughout the project. Their counsel was instrumental to the project's success. We also thank Worcester Polytechnic Institute for this opportunity.

Zachary Harmony

Erin Murphy

Jillian Proulx

Jeremy Soderholm

Licensure Statement

Professional licensure is an important distinction for an engineer. Earning licensure is a stringent and demanding process meant to protect the public by ensuring that all design is examined by a competent, educated, and qualified Professional Engineer. Not all engineers become licensed due to exemptions which allow an individual to work under a Professional Engineer. However, obtaining a professional engineering license provides many benefits and opportunities (NCEES, 2015).

In the United States, the steps to achieve engineering licensure vary slightly by state. The general process requires four steps defined by the National Council of Examiners for Engineering and Surveying (NCEES). The first step is to graduate with a degree in engineering from an Accreditation Board for Engineers and Technology (ABET) accredited program. ABET is an organization that ensures “a program meets the quality standards that produce graduates prepared to enter a global workforce.” (ABET, 2016). Upon graduation the aspiring Professional Engineer must pass the Fundamentals of Engineering (FE) exam administered by the NCEES. If this exam is passed the aspiring Professional Engineer earns the title of Engineer in Training (E.I.T). The E.I.T. then needs to acquire work experience under a licensed Professional Engineer, to learn the acceptable practices of a Professional Engineer. Typically four years of work experience under a Professional Engineer are required; however, the required length of work experience varies by state, and in some states can be shortened by other methods, such as earning a Master’s degree. Once the E.I.T. has acquired this work experience, the final step towards becoming a Professional Engineer is to pass the Practice of Engineering (PE) exam. After this exam is passed the individual may apply for a professional engineering license in the state they plan on practicing (NCEES, 2016).

Becoming a Professional Engineer uniquely allows the individual to stamp and seal designs, be principal of a firm, perform consulting services, and bid for government contracts. The requirement of licensure for these opportunities means that those engineers who do not attain licensure do not have nearly the same advancement opportunities as a Professional Engineer (NCEES, 2016).

A professional engineering license is meant to ensure that the work for a project meets all the design, safety, and ethical requirements of the applicable codes. This license ensures the quality and sustainability of a project, as well as safeguarding the public from inadequate and dangerous designs and practices. Due to the stringent requirements of obtaining a professional license, any individual who becomes a Professional Engineer is immediately recognized as a capable and respectable engineer. However, to maintain licensure, the Professional Engineer needs to ensure that they continue to maintain ethical practices and that all their future designs are code compliant (NCEES, 2016).

Construction on this project could not start without the approval of a Professional Engineer. All the drawings and specifications for this project would need to be reviewed, and the drawings would need to be stamped and sealed by a Professional Engineer before construction of the building could be performed. Due to this requirement all projects rely on the approval of a Professional Engineer (NCEES, 2016).

Capstone Design Statement

This Major Qualifying Project focused on the design and analysis of a Campus Center in Gateway Park off Route 290 in Worcester, MA. A variety of related coursework prepared this Major Qualifying Project team for the necessary engineering work. This capstone design experience is an important stepping stone between school and becoming a professional engineer. It allowed for the application of previously learned skills to aid in the design of a building while also conforming to applicable building codes and engineering standards. The project contained architectural, structural, mechanical, and life safety design and addressed many real-world constraints including code and zoning restraints. Other constraints that were addressed included:

Health and Safety

A risk assessment and fire protection analysis was completed. This included both active and passive fire protection system designs and alternatives, which were designed using the *International Building Code* and *NFPA 101 Life Safety*. Structural engineering and zoning provisions also reflected health and safety requirements by following the provisions of the *International Building Code* and *Massachusetts Building Code*.

Environmental

Gateway Park is known to have contaminated soil from previous industrial use, which classifies it as a brownfield development. Hazardous waste and toxins need to be removed from the soil, which requires a safety level for specific occupancies. This constraint impacted the LEED certification considerations.

Economic

Different structural, mechanical, and fire protection alternatives were developed and analyzed. A cost estimate was completed to compare and contrast the feasibility of each design alternative in each area of design.

Constructability and Manufacturability

This building was designed by studying various systems to determine the best option. This was done to ensure the building's feasibility in regards to the materials used, the cost associated with the selected systems, and the building's overall size, height, and layout. This ensured that the building would be constructible in the built environment. This was done by primarily referencing the different sections of the *International Building Code.*

Ethics

Engineers assume a role of responsibility that requires high standards of honesty and integrity. In this project, we followed the NSPE Code of Ethics. Under the professional obligations, we strove to serve public interest at all times, acted as loyal agents for the client (WPI), and hold paramount the health, safety and welfare of the public. We have ensured that all aspects of the building meet the specifications of the building and professional codes.

Sustainability

LEED, or Leadership in Energy and Environmental Design, is a rating system for a building design's environmental consciousness and efficiency. In this project, the most current version of LEED, v4, under the Building Design and Construction category, LEED BD+C: New Construction was considered. Through different mechanical, daylighting, and architectural systems, we designed this building to achieve the level of LEED Silver.

Social

Currently, very little student life occurs in Gateway Park. The purpose of the building was to bring more students to this developing part of WPI's campus. To do this, the building was designed to combine student life with administration, providing this area of campus with new social opportunities.

Executive Summary

As WPI's campus continues to expand beyond Tech Hill, students and faculty require more spaces for resources and recreation. WPI's Master Plan for Gateway Park, an expansion of the main campus, includes adding a new building to the site at 1 Concord Street. WPI President Laurie Leshin addressed WPI's expansion and community presence in her inauguration speech, where she discussed WPI's role in impacting others on a global scale. She proposed changing the Institute's motto from "Theory and Practice," to "Theory, Practice, and Impact."

The purpose of this project was to create a useable and feasible space for students and faculty to gather. To create a cohesive space, a multidisciplinary team was necessary. The team was composed of two Architectural Engineers with a structural concentration, one Architectural Engineer with a mechanical concentration, and one Civil Engineer with a structural design concentration. Additionally, one of the Architectural Engineers with a structural concentration was in the process of pursuing a Master's Degree in Fire Protection Engineering, which greatly assisted in the design development phases. Each member contributed to the design with their various skills and experience.

To address the needs of WPI, the team determined its project goals:

1. Understand how a building is designed and coordinated
2. Develop an architectural design with energy analysis
3. Develop a structural design and analysis
4. Develop a mechanical design and building analysis
5. Develop a fire protection suppression system design
6. Develop a cost analysis

Architectural Design

The architectural design of the Gateway Campus Center sought to meet WPI's needs while exploring the relationship between engineering and architecture through "Impact". The building was designed as a physical representation of a structural analysis graph, showing a force acting on a plane and the resultant diagrams. This use of graphical elements allowed the team to explore structural limitations and how they affect or restrict architecture.

To fulfill these goals, the team designed two separate buildings to meet the purposes of both the student and faculty populations. The two buildings, titled the Student and Administration buildings, were joined by a tower in the middle, creating the Institute's third tower of Impact. The Gateway Campus center was placed in a highly trafficked area, and its presence would have lasting effects on both the WPI community and the Greater Worcester community.

The building program was divided by usage. The Student building housed larger spaces, used for gathering and recreation. On the first level, this included a lounge, dining area and kitchen spaces, and loading dock. The second level featured a game room, tech suites, and video game tech suites. The third level included a gym, dance studio, and locker rooms. The Administration building sought to create collaborative spaces for both student and faculty usage. The first level featured a small convenience store, coffee shop and seating, and lounge spaces. On the second floor, small administrative offices and conference rooms were designed. The basement floor included more tech suite spaces, as well as a fireplace lounge, and access to the outdoor patio.

Many programs were used in design development to create the Gateway Campus Center. Google SketchUp was utilized in the early design process to create a site model and massing model of an early design proposal. AutoCAD was then used to create more specific sizing for the building and to place a structural grid and develop early room placement. From AutoCAD, the plans were exported to Revit, where room locations were finalized and elevations, sections, and 3-dimensional views could be developed. An additional program was Rhinocerous 3D, a design software that allowed for versatile design development for the Tower. This model was later placed into the Revit Model.

Structural Design

The structural design for this project required the design of two separate systems. Types of loads considered for the project included gravity loads and lateral loads. A braced frame was used for the lateral system, which prevented building sway. The braced frame allowed an ideal balance between cost efficiency and the least impact on the interior flow of the building. Due to the unique configuration of the braced frame in the building, it became important to understand how the braced frame would react under lateral loads early in the design process. Ram Frame, a program created by the company Bentley, was used to understand the behavior of the brace wall. This program was also used to size the brace wall members and to determine the overall building sway due to the lateral loads.

The gravity system used for this project was partial composite beam and slab. This system utilizes a concrete slab placed over a composite steel deck supported by steel beams. An unshored construction approach was used to reduce the required construction time, while still maintaining reasonable member sizes and costs. The design process followed the load path. First, the required floor slab properties were determined based on the defined design loads. The partial composite, beams and girder were then designed to support the slab and decking. Next, the columns were designed to transfer the load from the structural framing to the foundation. One of the major concerns for this project was controlling the vibrations caused by the elevated gym. This was done by increasing the stiffness of the structural framing supporting the floor in accordance with guidelines published by the American Institute of Steel Construction.

The foundation system for this project utilizes reinforced concrete due to its cost efficiency and durability. This foundation system transfers the load from the columns to the soil. Concrete piers and spread footings are located under each column. For the portion of the building with a basement, cantilevered retaining walls were designed to resist the lateral force of the soil. In the part of the building without a basement, foundation walls and strip footings were used to reach the four foot depth required for frost protection.

Mechanical Design

The mechanical design of this building required the design of two separate and distinct systems. For the Student building, a traditional VAV system was selected with the use of a system selection matrix. The decision matrix took into account several important design criteria identified by the owner and other important parties. Additionally, the spaces of the Student building were much more conducive to VAV due to the large requirement of supply air.

Peak cooling and heating loads were calculated in reference to the building's orientation, thermal properties and locational factors. A central air handling unit was designed for the Student building using the peak mechanical load on a room by room basis. The rooftop equipment was sized and selected. Comprehensive duct work for the system was produced in a drawing set. The Student building mechanical design features exposed ductwork with sidewall duct diffusers. For return air, upturned duct 90 degree angles were used. The duct system is a single-duct VAV system with terminal heating. For spaces with large heating loads in the Student building, like the lounge on the first floor or the dance studio on the third floor, fan-powered VAV terminal boxes were selected to meet the requirements. For other spaces, single-duct reheat boxes were used. For the heating design of spaces with exhausted air, radiant ceiling panels were sized.

For the mechanical design of the Administration building, active chilled beams coupled with a dedicated outside air system (DOAS) were designed. The design featured the sizing and placement of active chilled beams in each space, along with mechanical drawings laying out ductwork and piping. The chilled beams were selected from Trox to handle the sensible mechanical loading of the space while the DOAS unit was selected to provide supply air to the conditioned space to meet the latent or ventilation requirement for each zone. Similar to the Student building, peak mechanical loads were determined with consideration for the building's orientation, thermal properties, and location information. For the pipe design of the active chilled beam system, a 4-pipe system was used to supply hot and cold water to the beams. An in-line pump was selected and the piping was sized due to head loss in the system and the pump pressure required. Similar to the Student building, several spaces used radiant heating ceiling tiles coupled with the exhaust system to properly ventilate the space.

Egress and Fire Protection Design

The egress design for this project incorporated the design of two separate buildings, the Student and the Administration building, that are connected by a horizontal exit in the form of a tower. Both buildings were analyzed separately, with the horizontal exit being a part of the Student building. In terms of egress requirements, both buildings were found to be of assembly occupancy, with some areas of business, mercantile, storage, and incidental occupancies. An assembly type occupancy has the most restrictive requirements, so the design of the buildings needed to take into account the different building and design limitations. Occupant load calculations were completed to determine the size and number of exit components. The maximum occupant load for a floor was seen in the Administration building basement, with a total of 305 people. This determined that the minimum number of exits per floor would be two. Floor levels other than the ground level incorporated the main open stairs into the egress design, as well as one exit stair per building. The minimum exit width for the stairs was calculated to be 45 inches for the Student building and 46 inches for the Administration building, with both buildings having a minimum door width of 36 inches. The common path of travel for a sprinklered assembly occupancy is 75 feet. The final egress design check ensured that the buildings adhered to the required travel distance for assembly type spaces.

This project incorporated a fully sprinklered building. NFPA 13 was consulted during the sprinkler design process. Due to the full conditioning of both buildings, a wet pipe systems was chosen for the sprinkler system type. Roll Grooved Schedule 10 Black Steel Pipe was used for the installation. In regards to sprinkler system design, both buildings were considered to be primarily of light hazard occupancy classifications, ordinary and extra hazard classifications in small areas of each building. The maximum commodity classification was Group A Plastics. These characteristics permitted the use of sprinklers with a k-factor of 5.6 and a discharge density of 0.1gpm, 0.15gpm, or 0.2gpm over a design are of 1500sqft throughout most of the building areas. Areas that were considered to be of extra hazard occupancy, such as the water pump and mechanical rooms, incorporated sprinklers with a k-factor of 11.2 and a design density of 0.3gpm over 2500sqft. The design pressure and flow were below the city water main pressure and flow and no fire pump was needed. The cost for the designed sprinkler system was calculated to be approximately $128,000, or $4.55 per square foot of floor area.

Cost Analysis

A general building analysis was completed using *2011 RS Means Square Foot Costs*. Once determining the construction type of the building and other additives such as elevators, the total square footage of the Gateway Campus Center was multiplied by cost per square foot. The result was then prorated to 2015 values and multiplied by the Worcester location factor of 138.6. By doing this, a generalized building cost of $7,154,434.16, or approximately $7.2 million, was determined.

Once the structural design was completed, a cost analysis was performed using average cost per unit of each of the components for the overall structural system. This total was then adjusted to more accurately reflect the Worcester area by using a predetermined location factor. The total estimated cost for the structural system, adjusted for Worcester, was approximately $850,000. This equates to approximately $30.27 per square foot. This value was above the original expected structural cost, of $25.48 per square foot, due to the increased framing required for the elevated gym floor.

Using the total building cost determined from *2011 RS Means Square Foot Costs*, the cost of the mechanical or HVAC systems of the building were calculated. This cost estimate was used by taking the percentage of total cost for the HVAC system for a Student Union in the *2015 RS Means Square Foot Costs* book. Therefore, the total cost for the mechanical systems of the building are approximately 16.3% of the total building cost or $1,116,172.77, close to $39.86 per square foot.

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1.0 Introduction

1.1 Project Motivation

Worcester Polytechnic Institute (WPI) is a center for higher education located primarily between the streets of Institute Road and Salisbury Street. Gateway Park is an expansion of the campus, intended to accommodate more centers for research and learning. In this growing community, there lacks a central location for student life. As Gateway Park expanded with the addition of the new residence, Faraday Hall, a need developed for a new communal center close by. Accordingly, a new campus center is being proposed to further unite the WPI community in Gateway Park.

In WPI President Leshin's inaugural address in the Fall of 2014, a third tower inspired by Impact was implemented into the school's motto "Theory and Practice". As one of the nation's first engineering and technological universities, WPI has the ability to affect people on a global scale. This vision of President Leshin furthered the motivation for the Gateway Campus Center; the addition of a third tower indicated the need for a new building. WPI is known for the two towers located on campus, featured at Boynton Hall and Washburn Labs. A campus center at Gateway Park featuring this third tower would also unify these two separate areas of WPI's campus.

1.2 Design Concept

The design concept of the Gateway Campus Center explored the way architecture is defined by structure and the feelings evoked from the architecture's interaction with structural limitations. In this project, the driving concept was Impact – how a force affects existing conditions and redefines the space around them. Impact redefines the spaces, and the structure withstands this force of Impact. The proposed building has three sections: an academic section, a student section, and a connecting tower. The tower in this proposed building is the "Impact Tower" and affects the physicality of the structure and architecture. The design is intended to represent a force driving into the site and 'impacting' a pre-existing structure.

The building design mimics shear and moment diagrams to represent the "impact" that the "force" of the tower has on the structure. The tower is a visual representation of a point force on a beam that is fixed on both ends. The tower is not centered evenly between the two buildings, further emphasizing the disruptive and asymmetric effect of the force. The value of the force is 150 kips for the number of years of WPI's existence at the time of President Leshin's inauguration. The academic building is two stories high and has a sunken basement level below grade, while the student building is three stories high. This mass was determined using the resultant shear diagram, as seen in Figure 1. A brace wall cutting through the two buildings, cut off by the impact tower, represents the resultant moment diagram.

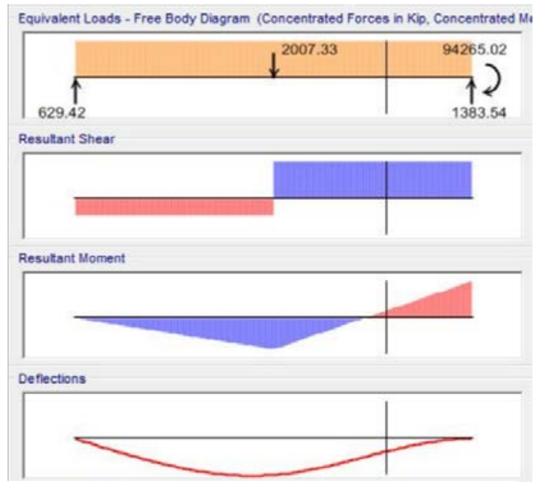

Figure 1: Shear and Moment Diagrams

The brace wall was critical in designing both the structural plans and architectural program. Once the mass of the building and the placement of the brace wall were determined, multiple structural plans were developed to create options that best fit the needs of the two buildings.

The concept of Impact was utilized throughout the design process. In initial design development, it was used for massing and structural grid development. Floor plates were designed to look as though they had been cut away by the driving force, creating atrium spaces where the tower interacted with the building. The window placement was also representative of the effects of Impact. Windows were placed more frequently closer to the center of the Impact Tower, growing less frequent toward the ends of the building. These design choices further impressed the effects of Impact on the building's final design.

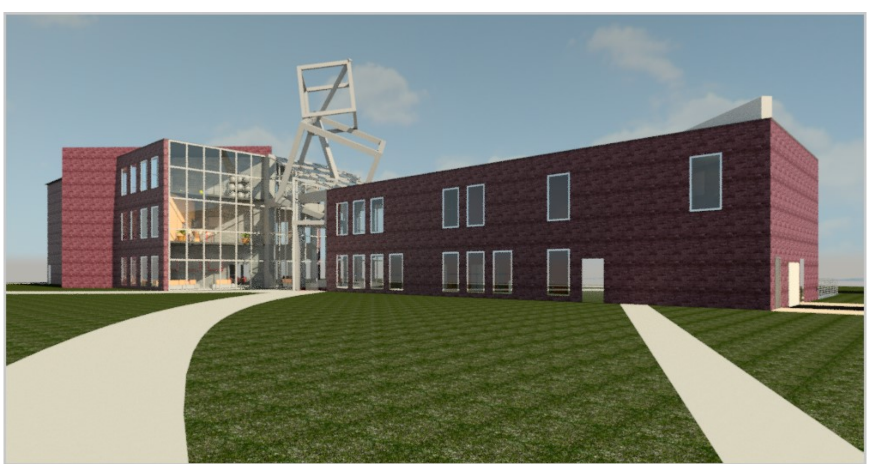

Figure 2: Exterior Rendering of Gateway Campus Center

1.3 Report Organization and Governing Codes

For a building to be in compliance and be approved by the Authority Having Jurisdiction, certain codes must be adhered to. Codes that are important to and are used in the design of the Gateway Campus Center are primarily:

- *2009 International Building Code IBC*, with Massachusetts Amendments
- *2009 International Mechanical Code*
- *2009 International Fire Code, IFC*.
- *National Fire Protection Association, NFPA 13*: Automatic Sprinkler Systems
- *National Fire Protection Association, NFPA 101*: Life Safety Code

2.0 Site

WPI's Gateway Park, which opened in 2007, is an area of campus dedicated to research and innovation. Up until the 1950s, this region was populated with mills that thrived in the Industrial Age. When production shifted to other parts of the globe, these mills were abandoned. Gateway Park is 63 acres, 11 of which are owned by WPI. The Park is part of a Brownfield development within the industrial district of Worcester. Today, the two buildings in Gateway serve as student academic buildings and office buildings for related industry offices. The proposed campus center will help tie Gateway to the rest of WPI, bridging campus life with this growing region.

The specific site chosen within Gateway Park is a square lot between WPI's new residence Faraday Hall and WPI's two professional buildings located in Gateway Park. Other sites were considered, including the adjacent lot and areas of Institute Park, located just up the street. The proposed site for the Gateway Park Campus Center is One Concord Street, a lot that is approximately one and a half acres. The proposed building will serve as both a community building where students and faculty can gather and socialize, as well as an administration building with offices, tech suites, and conference spaces.

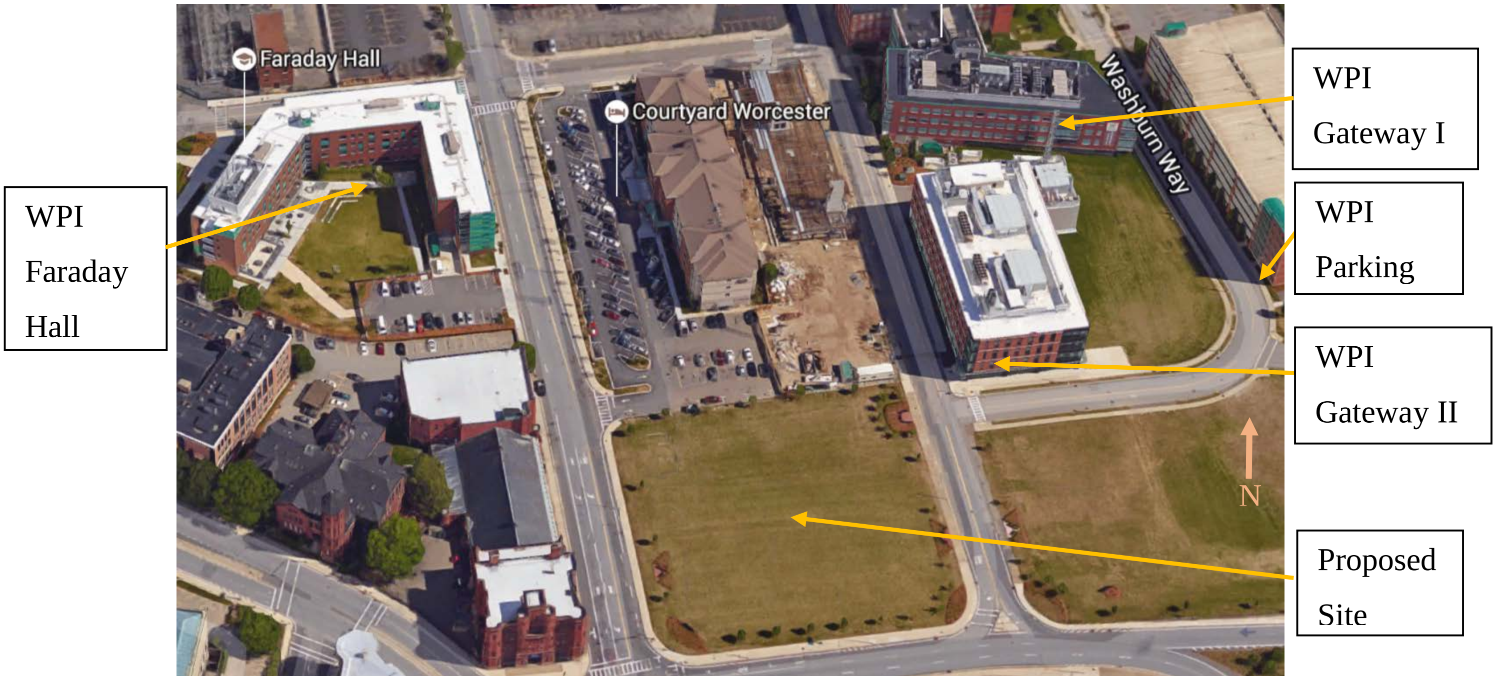

Figure 3: Building Site

2.1 Building orientation on the lot

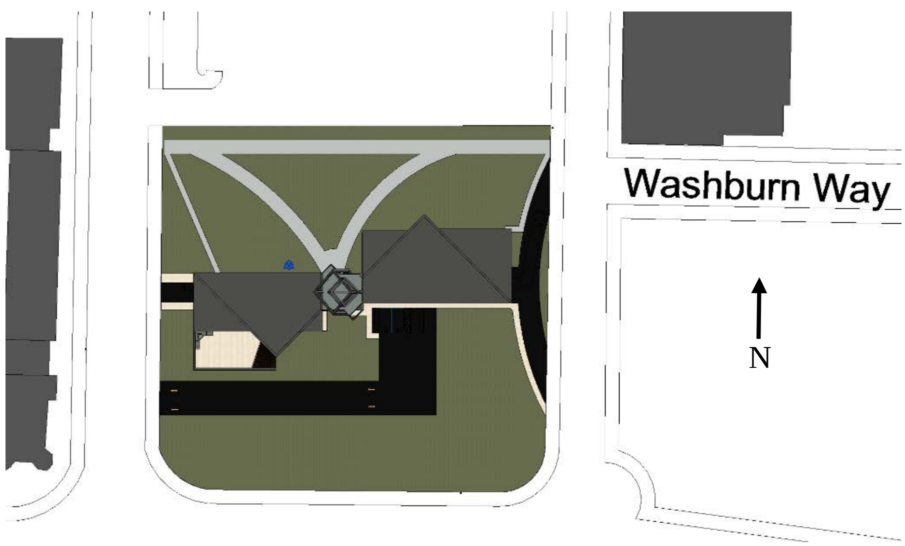

Figure 4: Site Plan

The building was positioned towards the northern end of the lot. The main entrance was placed on the north side of the building, with a small parking lot for handicap and electric vehicles on the south side. Loading dock access was provided on both the east and west ends. Deliveries on the west were intended for smaller packages, while larger deliveries were intended for the larger loading dock on the east end, where a semi-circle driveway was placed for tractor trailer truck access.

2.2 Zoning Considerations

The proposed site is located in zone BG-6.0, which is classified for Business, General usage. The permissible Floor-Area Ratio (FAR) is six square feet of building per square foot of land. The zoning has setback limitations of ten feet at the rear and no limitations for the front and sides. The proposed building and its placement met these limitations.

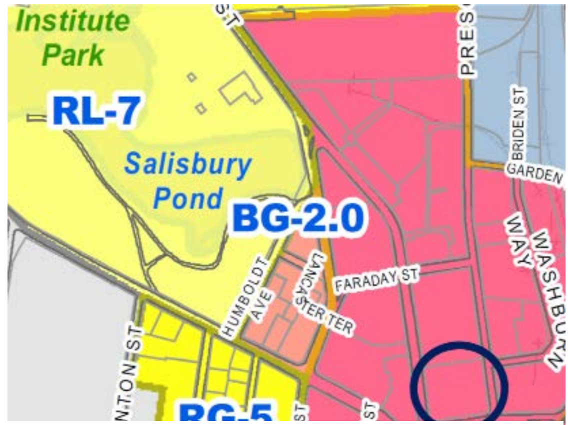

Figure 5: Zoning

2.3 Geotechnical Considerations

The proposed site of the Gateway Campus Center was previously used for manufacturing. As a result of this, the site was exposed to hazardous substances and contaminants, leading to its classification as a “brownfield.” A brownfield is defined by the Environmental Protection Agency (EPA) as “a property, the expansion, redevelopment, or reuse of which may be complicated by the presence or potential presence of a hazardous substance, pollutant, or contaminant” (Environmental Protection Agency, 2015). The brownfield at the chosen site was remediated to a certain level and pads were established for new construction.

To determine realistic geotechnical characteristics for the site, a geotechnical report for the adjacent building developments was used. This geotechnical report was performed by Maguire Group Inc. in 2005. This report did not directly address our building site; however, it did include a boring log in the immediately adjacent lot. This boring log was compared to a second boring log from a building site directly addressed in the report to determine if the soil profiles were roughly similar. After determining that the two profiles consisted of the same soil types, with only very slight differences in the density of the soil, it was concluded that this report could be used to approximate the geotechnical conditions for the building site.

3.0 Architectural Design

The architectural design phase determined the locations of spaces to fit the occupational use, and aesthetic needs of the building. In order to fit the needs of two very different spaces, the Gateway Campus Center was divided into two buildings, the Student and Administration, which were separated by the Tower, which acted as a lobby space and entryway into each building. The Student building was characterized by larger, more open spaces with more assembly areas. The Administrative building had smaller office spaces and private areas. In this section the architectural design, construction type, and building envelope considerations are discussed.

3.1 Architectural Design

The architectural design approach was to explore how architecture is defined by the physical limitations of structure. Structure withstands the force of the Impact and defines the architectural program and circulation within the building. This concept was developed through the use of shear and moment diagrams as a result of a force impacting the building. General massing was developed using Google SketchUp.

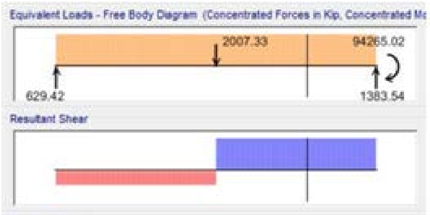

Figure 6: Shear Diagram of Force

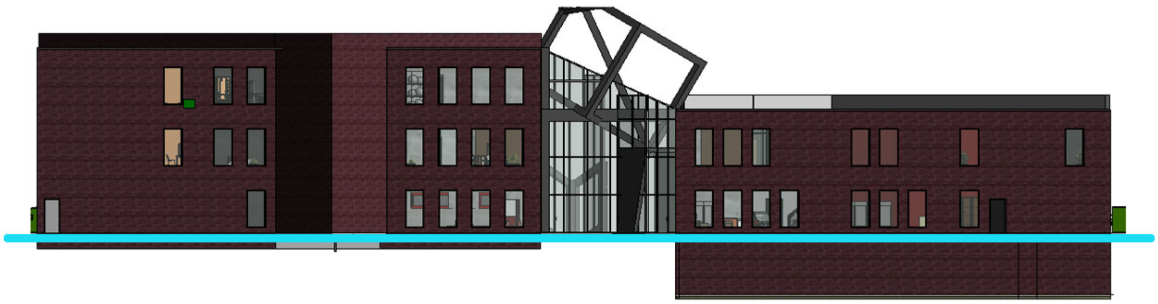

Figure 7: North Elevation of the Gateway Campus Center

In elevation from the North or South sides, the building mass mimics the shear diagram. In the diagram, as seen in Figure 1, a larger portion of the shear force occurs above zero, and a smaller reaction occurs below zero. To artistically represent this, the Student building, shown on the left in Figure 7, was placed entirely above grade. To complement this, the Administration building, shown on the right in Figure 7, was lowered to include a below-grade level. Ceiling heights were also defined to mimic this representation. In the Student building, ceilings were 13 feet high on each floor, allowing for more open spaces. In the Administration building, a finished ceiling was placed at 9 feet on each floor, emphasizing the feeling of being more enclosed, as seen below in Figure 8.

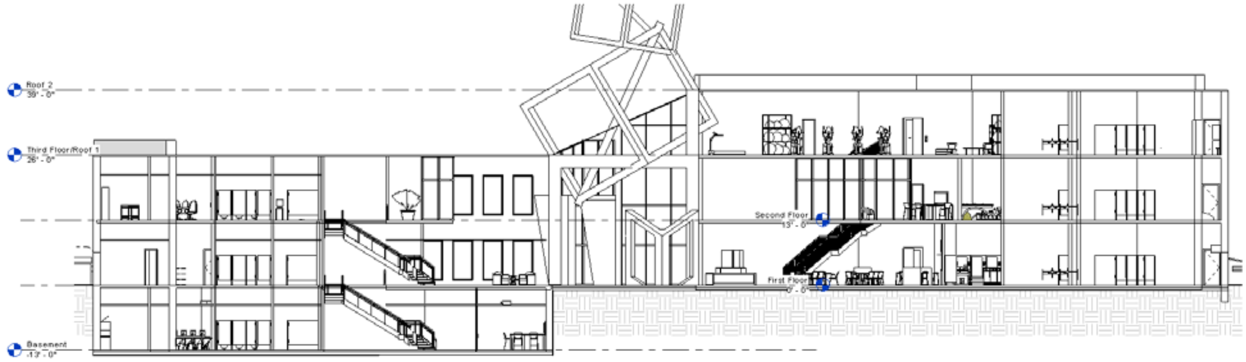

Figure 8: Section - Ceiling Height Comparison

Locations of programmatic elements were determined by functionality and their relation to either student social life or administrative activities. Bubble diagrams were used to determine tentative places for each component of the program. These were then shaped by the brace wall and followed code for sizing areas. Floor plans were initially developed in AutoCAD, due to the program's two-dimensional flexibility. Once general massing was developed, the plans were moved to Revit, where the building was framed and the architectural layout was completed. In Revit, window placement was determined. Windows were designed to mimic the effect of force, creating more openings closer to the point of impact and receding towards the east and west ends. This can be seen in the North Elevation in Figure 7.

The Administration building was designed to have communal spaces on the first and basement floors, with private office and conference spaces on the second floor. The first level of this building includes mercantile coffee and convenience store spaces, a lounge, and storage areas. The basement level includes a lounge with a fireplace

Figure 9: Administration Basement Rendering

presentation area and access to an outdoor terrace, tech suites, a pump room, and outdoor storage. The second floor includes conference rooms, offices, a janitor's closet, a resource area, and a lounge. The entryway on the first floor near the tower is open to the first and second levels, emphasizing the effect of the Impact driving into the building. As the building recedes to the outer ends, the rooms become more closed off. These features demonstrate the "impact" that the tower has on opening up the building. The architectural floorplans can be seen in Appendix K: Drawings.

The Student building implemented greater areas for socializing and gathering. To create this feeling of community, larger and more spacious areas were designed for an open floor plan. The first level of this building contained a food seating area with an attached kitchen, a small lounge seating area, a pump room, and a loading dock. The second level includes a gaming area, a video gaming area, and tech suites. The third level of this building houses a gym with locker rooms and a dance studio. Much like the Administration building, the areas closer to the tower are more open with the areas further away from the tower being smaller and closed off. This building also had a cutout in the floor near the tower, connecting the first and second floors. The architectural floorplans can be seen in Appendix K: Drawings.

Figure 10: Student Building Entryway

3.2 Tower Design

The two towers, Boynton and Washburn, on WPI's campus symbolize the two founding principles of the Institute: Theory and Practice. On the 150th anniversary of the Institute, and with the inauguration of WPI's 16th President, Laurie Leshin, a third "tower" of impact was added to the school's motto, becoming "Theory, Practice, and Impact." The Gateway Campus Center seeks to incorporate this ideal through a physical tower. In this section, the function and representation of the tower is discussed, along with its structural and mechanical needs.

3.2.1 Architectural Reasoning

The tower was designed as the focal point of the building. Three boxes, each representing one of the principles of the motto, crashed into each other, creating a dynamic piece that functioned structurally and architecturally. The top box symbolized Impact, as it was the first piece to initiate the force and its effects. The middle box symbolized Theory. Its off-kilter placement imitated the imperfection and experimental nature of Theory. The bottom box symbolized Practice and its straightforward, repetitive and solid nature.

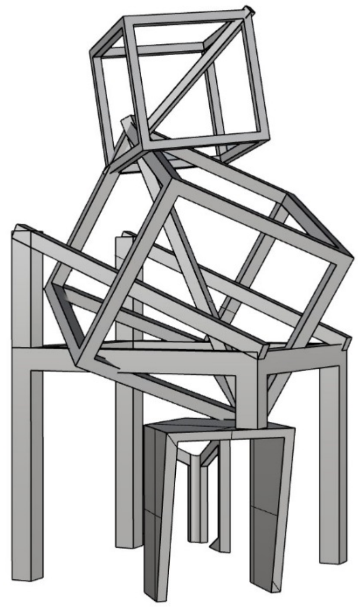

Figure 11: Tower Model

By having each of WPI's principles intertwined with each other, the tower became a functional space that allowed the user to interact with a physical representation of the Institute's core values. The tower was constructed as a skeletal structure to show the relation of each value with the other.

3.2.2 Functions and Design

A large component of the architectural design of the Gateway Campus Center included the implementation of WPI's third tower, called the "Impact Tower." Inspired by the graphs used in structural engineering to calculated forces and the resultant reactions on a beam, the Impact Tower was designed as an abstracted representation of a force. The tower represented a force acting on a surface, and the massing and layout of the building was affected by the force, changing the physicality of the structure and architecture of a pre-existing structure. Although there was no pre-existing structure at the site, the design sought to create the impression that two buildings had been struck by a force, ultimately separating the Student and Administration buildings with a shear cut.

The "impact" of the tower affected both the Student and Administration buildings of the Gateway Campus Center. Within each building, the entryways, which each parallel the tower angles, were two stories high. This represented the tower's effect on the respective buildings being most forceful when closest to the tower's point of impact. Additionally, window placement represented the effect of the tower, creating openings in the existing structure. On the exterior walls that came into contact with the tower, a glass façade was placed to emphasize this effect. As the building recedes from the point of Impact, the windows occur less frequently. At each end of the building the walls do not have any glass.

The Impact Tower was constructed of glass with steel bracings. HSS sections were used for the top two boxes of the tower, and wide flange beams and columns were used for the base box. In order to retain the similarities of each box, the bottom box encased each wide flange beam or column in a 2.5'x2.5' box. A shed roof was placed at the center of the middle box, angled between the higher roof of the Student building (39') and the lower roof of the Administration building (26').

The Impact Tower acted as a main entry space to connect the two buildings.

Figure 12: Interior Tower Rendering Looking Into Student Building

3.2.3 Structural Problems and Solutions

Due to the change in materials and design between the two buildings and the tower, the tower was designed as a separate structure. This allowed lateral forces to be applied to the tower and resisted independently of the other buildings. As a result, the Impact Tower, Student building, and Administration building each have separate structural systems. Because of this, the buildings and the tower will not displace by the same amount when affected by lateral forces, especially seismic. If this phenomenon is not addressed in the structural design, the buildings can be damaged by pounding. A separation joint was used between the tower and the two buildings, allowing the three buildings to move independently of one another while avoiding damage. The size of this separation joint was determined by the building sway caused by the design loads, for wind and seismic effects. The design process for the individual steel members was similar to those described in Section 4.3.

3.2.4 HVAC Problems and Solutions

One of the major difficulties with the mechanical design of the building was the integration of the tower into the system design. Due to the structural and fire protection restrictions to the tower, the fact that the "Impact Tower" was its own structure, made it difficult to tie it into either of the mechanical systems used for the buildings. Further consideration should be taken to determine how to effectively heat and cool the tower.

Another problem presented by the building was the multi-use of the spaces, due to the comprehensive architectural program of the building, many uses and needs had to be met by the mechanical design. This coupled with the decision to create two different systems for each building made the coordination and design of these systems difficult. The multiuse and the high solar loads brought by the tower create several different requirements for a system which were difficult to find in one all-encompassing system. Heating and cooling load calculations will be developed similar to the process detailed in Section 6.1. Upon evaluation of several problems that the HVAC design for the tower would face, further investigation and/or work must be done to determine an ideal system for the tower.

3.4 Construction Type and Building Limits

The building was designed using Type IIA construction. This type of construction utilizes protected, noncombustible materials. Type A indicates that the building has fire rated elements, whereas type B has building elements that are not required to be fire resistant but must still be non-combustible. Construction type affects the fire protection rating of the structure. It determines the fire resistive rating (in hours) for various components of a building. The values for this building can be seen in Figure 13. In Type IIA, the fire resistant components include one-hour fire resistive exterior and bearing walls, structural frame, and floor and ceiling protection. Typically, Type IIA buildings have masonry walls with steel studs and bar joists. The Gateway Campus Center followed this trend and was designed with steel framing and a brick veneer.

Building Element	Required Fire Resistance Rating (hours) Type IIA Construction per IBC 2009
Exterior Bearing Walls	1 (Table 601)
Primary Structural Frame	1 (Table 601)
Floor Construction and Secondary Members	1 (Table 601)
Roof Construction and Secondary Members	1 (Table 601)
Stair/Elevator Shaft	1 (1022.2)

Figure 13: Fire Resistive Ratings

Within the program, assembly spaces were considered to be the most restrictive. The specific subcategories of Assembly type spaces can be found in the *International Building Code* Section 303, and the ones used for this particular structure include A-2, assembly uses intended for food and/or drink consumption, and A-3, assembly uses intended for worship, recreation, or amusement and other assembly uses not classified elsewhere in Group A, such as lecture halls without fixed seating. This limited the building to three stories at a maximum of 15,500 square feet per story and a maximum building height of 65 feet. This was determined by using Table 503 in the *International Building Code*. The proposed building had a footprint of approximately 10,100 square feet, with a maximum of three stories and maximum building height of 39 feet.

TABLE 503 ALLOWABLE BUILDING HEIGHTS AND AREAS[a]

Building height limitations shown in feet above grade plane. Story limitations shown as stories abo

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

Figure 14: Allowable Building Heights and Areas

Due to the architectural and structural components, the Impact Tower was taller than 65 feet. Because of this, the tower was designed to have both enclosed and open spaces. The enclosed area was nested between the Student and Administration buildings with a shed roof connecting the two roofs, rising from 26 feet to 39 feet. From the surface of the shed roof to the top of the tower, the remainder of the structure was open. Because this space was uninhabited, there were no restrictions on the height of the tower. This was allowed because the enclosed, inhabited area of the tower is the height of the student building, which is below 65 feet. The building height and area were within the requirements per code.

3.3 Plumbing Considerations

Bathroom requirements were determined using Table 2902.1 in the *IBC*. These were done for each of the floors in each of the two sections of the building. The number of toilets and sinks was determined from the number of occupants per floor using the exit egress findings. Table 2902.1 specifies how many sinks and toilets per person are required for assembly type occupancy. Assembly was used because it is the most restrictive occupancy of the ones necessary building, and it also represents the majority of the floor area. The number of toilets and sinks can be seen in the following table.

				Water Closets		Needed 50/50		Lavatories		Needed Per	
Building	Level	Occupancy Type	# of People	Male	Female	Male	Female	Male	Female	Male	Female
Administration	Basement	A-3	305+25	1 per 125	1 per 65	1.3	2.6	1 per 200		0.8	
	1	A-3	265			1.1	2.0			0.7	
	2	A-3	217			0.9	1.7			0.5	
Student	1	A-2	300	1 per 75	1 per 75	2.00	2.00	1 per 200		0.8	
	2	A-3	297	1 per 125	1 per 65	1.2	2.3	1 per 200		0.7	
	3	A-3	81			0.3	0.6			0.2	

Figure 15: Plumbing Calculations

		Male	Female
Administration	Basement	2 toilets with 1 sink	3 toilets with 1 sink
	1	2 toilets with 1 sink	2 toilets with 1 sink
	2	1 toilet with 1 sink	2 toilets with 1 sink
Student	1	2 toilets with 1 sink	2 toilets with 1 sink
	2	2 toilets with 1 sink	3 toilets with 1 sink
	3	1 toilet with 1 sink	1 toilet with 1 sink

Figure 16: Sink and Toilet Requirements

3.5 Exterior Considerations

The proposed Gateway Campus Center was placed in the industrial region of Worcester within WPI's Gateway Park. This area, which formerly was an industrial hub, is populated with many old factories and mill buildings. As WPI's campus has grown since 1865, the school buildings have been similarly constructed to include variations of brick with stone or concrete. To fit in with the architecture of the old factory buildings and with WPI's main campus, the Campus Center was designed with a brick veneer on a metal stud wall. The tower was made of glass, with black steel as the supporting structural features.

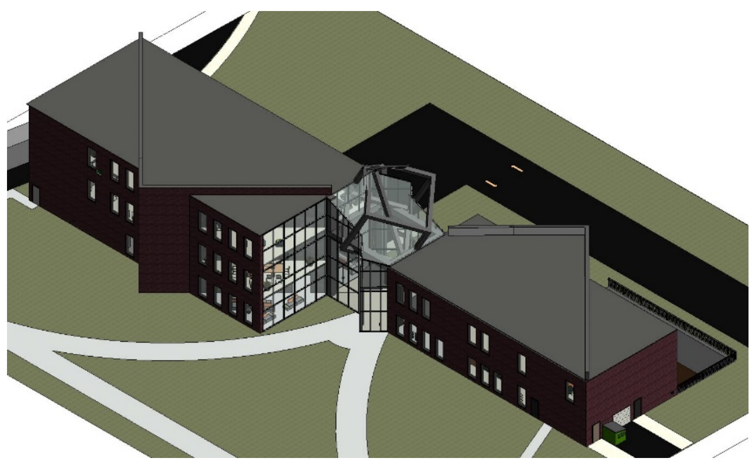

Figure 17: Facade

One of the "impacts" of the tower is the spacing of the windows. In the Student and Administration buildings the walls that come into contact with the tower are curtain walls, mimicking the effect of the Impact cutting away existing structure. From that central point, the windows on the north and south walls for both the Student and Administration buildings were placed to further emphasize the effect of Impact. Windows were placed less frequently as the building gets closer to the East and West exterior walls. The ends of the building did not have any windows, creating the illusion of the tower opening up the building.

3.6 Envelope Energy Code Compliance

The envelope of the Gateway Campus Center must comply with the requirements of the *Massachusetts State Building Code 780 CMR*, which incorporated the *2012 International Energy Conservation Code (IECC)*. Commercial construction must comply with the commercial provisions within the *2012 IECC* or *ASHRAE 90.1 2010*. COMcheck Software was used to determine that the proposed building met energy code compliance for Massachusetts. COMcheck is a tool provided by the U.S Department of Energy to help engineers, designers, contractors and others to determine whether new commercial buildings, additions, or alterations meet the requirements of the *IECC* and *ASHRAE Standard 90.1*, while also ensuring the building meets state-specific codes. A quick analysis through COMcheck without reference to interior/exterior lighting or mechanical systems determined whether or not the envelope of the building was code compliant.

3.7 Effect of Building Shape on HVAC

The unique shape of the building lends itself as a challenge to the mechanical design engineer. The building is essentially two separate buildings connected by the tower or glass structure in the middle. The tower serves as an entry lobby and has one floor. The Student building, on the right in Figure 14 below, has three floors above ground, and the Administration building, on the left in the image, has two floors above ground, with one basement floor.

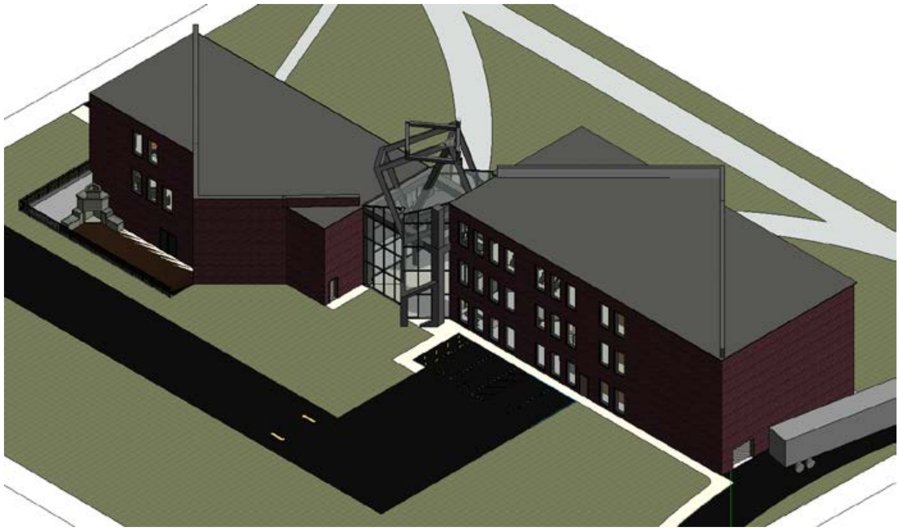

Figure 18: Isometric view of building exterior

Due to the nature of the building, and that it essentially acts as two separate buildings, the mechanical system was designed this way. The use of the spaces within the Administration building were conducive to the use of active chilled beams, while for the Student building, the use of the space was not. The Administration building has several smaller office spaces or tech suites that do not require a large amount of outside air and can take advantage of the secondary capabilities of an active chilled beam system. The large spaces and large ventilation requirements in the Student Building make it difficult to use active chilled beam. The gym and cafeteria spaces are better suited as a VAV application because of this. Similar to the Student building, and the nature of the entry way "lobby" of the tower, a large amount of air was needed to offset the infiltration loss from the doors constantly opening and closing. That and the large solar loads placed on the space made it a much more suitable application for VAV. Once the mechanical loads were determined for the sizing of the mechanical systems, two separate systems, one for each "building", were designed to condition the space. The tower would ideally be grouped with the Student building and zoned independently from the Student and Administration buildings.

3.8 Cost Analysis

A general building cost analysis was completed to determine an average cost of the Gateway Campus Center. This was done to determine whether the separate cost analysis calculations for the structural, mechanical, and fire

2011		Location Factor= 110.1
Building Cost	$5,151,682.40	$ 5,672,002.32
2015		Location Factor= 138.6
Building Cost	$5,161,929.41	$ 7,154,434.16

Figure 19: Building Cost Analysis

protection were appropriate, relative to their respective percentages of the total building cost. The general building cost analysis was completed using *2011 RS Means Square Foot Costs*. Once determining the construction of the building and additives such as elevators, the cost per square foot was multiplied by the total square footage. The result was then prorated to 2015 values and multiplied by the Worcester location factor of 138.6. By doing this, a generalized building cost of $7,154,434.16, or approximately $7.2 million, was determined.

4.0 Structural Design

The structural framework of a building reinforces its shape and supports the applied loads. The framework also needs to provide a level of comfort to those occupying the building, which includes limiting vibrations, floor deflections, and lateral movement or sway. In the structural design, the strength and stiffness requirements for the foundation, member types and sizes, framing configurations, and connections were all considered.

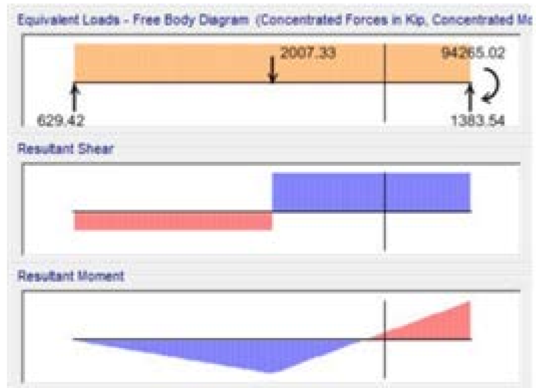

Figure 20: Moment Diagram for Brace Wall

The structural design of the Gateway Campus Center was based on the initial architectural design. The initial architectural design concept of Impact shaped the main structural component, the brace wall, which followed the contours of the Moment diagram as seen in Figure 20. After the preliminary layout was completed, the structural and architectural designs were developed together in an integrated manner. This approach allowed for better coordination for a number of factors, such as spaces in which there were many walls to hide structural columns, assembly areas that needed an open floor layout, and how rooms were placed around the brace wall.

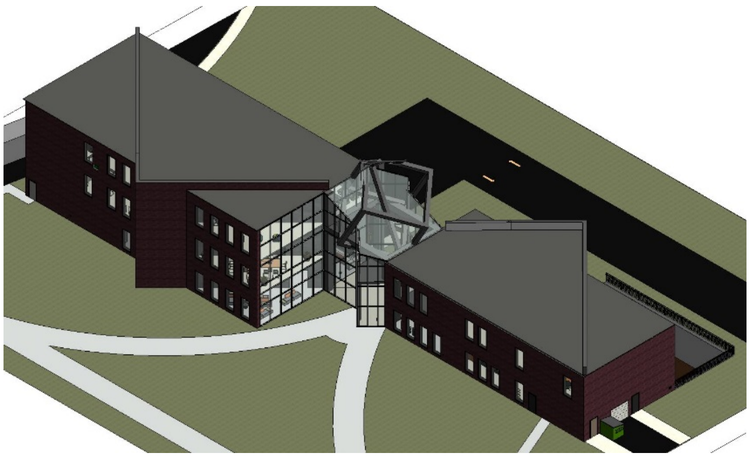

Figure 21: Brace Wall

Structural steel was the primary material used in the structural design of this building. Steel allows for faster construction times as opposed to cast-in-place, reinforced concrete. It also allows for lighter structural systems and longer spans. This typically permits less expensive foundation systems and fewer columns. Due to its wide-spread availability and durability, steel was utilized for both the gravity and lateral framing systems.

4.1 Structural Layout

When designing the structural layout of the building, many special design considerations were taken into account. For example, once the initial brace wall had been coordinated with the architectural concept's Moment diagram, column spacing needed to provide the least impact on the floor plans, while limiting the beams and girders to economical spans. The brace wall must support both gravity and lateral loads, while limiting its thickness to allow for more usable floor area. With these factors in mind, a structural grid was created to easily identify locations inside the building and to help expedite the construction process. The structural grid was governed by intersections with the brace wall. Each column is located at the node of two gridlines. This allowed each column to be easily identified based on the intersection. For example, the column located at the intersection of gridlines A and 4 is identified as column A-4.

Multiple grid layouts were developed for each building. The selected grids for the Administration and Student buildings can be seen in Figure 22 and Figure 23, respectively. The grid layout for the Administration building was selected based on only two designs due to the nature of the floor plan. The grid layout for the Student building was more complicated to establish due to the open floor plan and the larger building dimensions. The selected structural grids allowed for the optimal structural system based on the expected development of the architectural layout. It limited the total number of columns required without causing the columns to become cumbersomely large. The structural grids were selected with input from all disciplines in order to ensure they would not cause future coordination concerns. The options evaluated, along with a brief discussion of the reasons behind the selections, can be found in Appendix B.

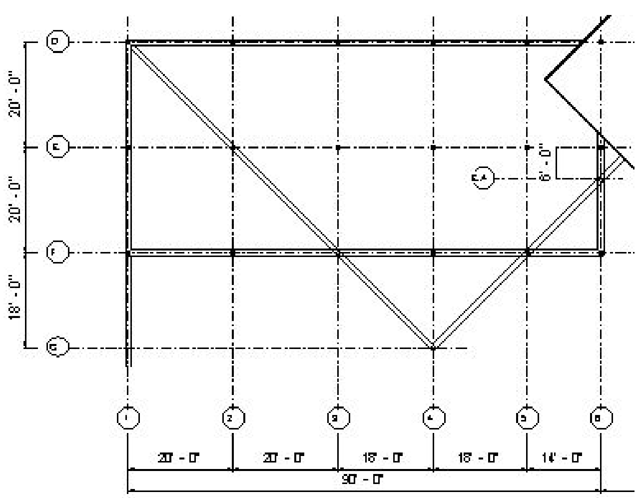

Figure 22: Selected structural grid for the Administration Building

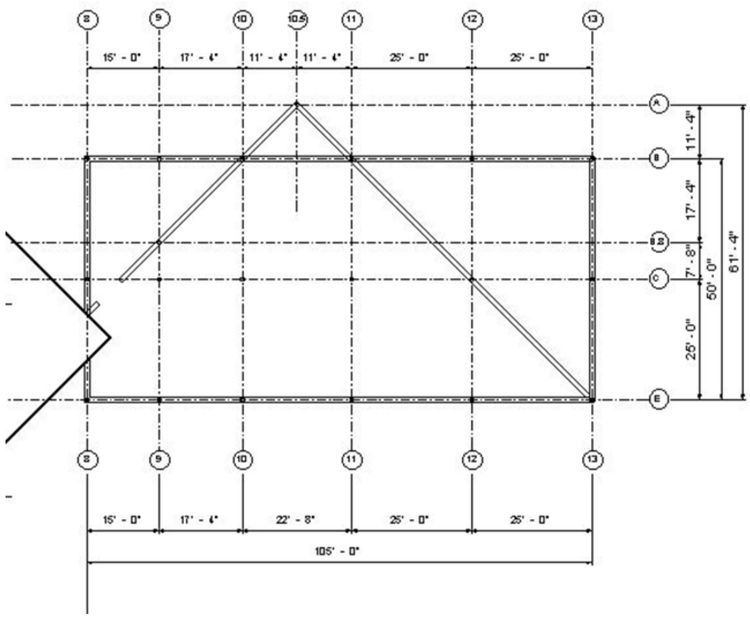

Figure 23: Selected structural grid for the Student building

4.2 Structural Loads

Loads represent the forces the structural framing is required to support and carry. Various types of loads are treated differently within the structural design provisions of the *International Building Code*. The two categories of structural loads considered for buildings are: gravity loads, which act in the direction of gravity or vertically on the system, and lateral loads, which principally act in any direction orthogonal to the gravity force or horizontally on the system. When using the Load and Resistance Factor Design (LRFD) approach, load combinations are applied to determine the basis for design. These load combinations account for overloading situations where the loads experienced are higher than the nominal design values. All the combinations must be explored, and the most critical combination is the one used in the design. The LRFD load combinations are as follows (American Institute of Steel Construction, 2013):

- $1.4D$ (1)
- $1.2D+1.6L+0.5(L_r \text{ or } S \text{ or } R)$ (2)
- $1.2D+1.6(L_r \text{ or } S \text{ or } R)+(0.5L \text{ or } 0.5W)$ (3)
- $1.2D+1.0W+0.5L+0.5(L_r \text{ or } S \text{ or } R)$ (4)
- $1.2D+1.0E+0.5L+0.2S$ (5)
- $0.9D+1.0W$ (6)
- $0.9D+1.0E$ (7)

Table 1: Summary of load types

Symbol	Name	Load Type	Description
D	Dead Load	Gravity	Permanent, fixed force in the same location for its lifetime
L	Live Load due to Occupancy	Gravity	Non-permanent forces that will change location or magnitude
L_r	Roof Live Load	Gravity	Non-permanent forces that will change location or magnitude, acting only on the roof
S	Snow Load	Gravity	Force from snow accumulation, specific to a buildings geographical location
R	Ponding Contribution	Gravity	Force due to the accumulation of water or ice caused by a blockage of the drainage system
E	Seismic Load	Lateral	Force from a seismic event, specific to a buildings geographical location
W	Wind Load	Lateral	Force due to wind acting on the structure, specific to a buildings geographical location

Structural loads were calculated using the *2009 IBC* and *Minimum Design Loads for Buildings and Other Structures* (referred to as *ASCE 7-05*). Most loads were determined in pounds per square foot (psf). For member design, these loads were converted to pounds per linear foot (plf) by multiplying the psf value by the tributary width of the member being designed. A brief discussion of tributary width along with examples can be seen in Appendix C. The nominal value of each load can be seen in Table 2. These nominal values were then placed in the load combinations shown previously (American Institute of Steel Construction, 2013). The largest value from these load combination was then used as the design loading, W_U. The controlling load combination for most of the structural members of this project was Equation 2 above.

Table 2: Summary of load magnitudes

Symbol	**Value for Each Building**		**Determined Using**
	Administration	**Student**	
D	weight of the beam + weight of the slab + 10psf (for mechanical and electrical equipment)	weight of the beam + weight of the slab + 10psf (for mechanical and electrical equipment)	Actual weight of the supported elements
L	• Basement: 80 psf • First Floor: 100 psf • Second Floor: 80 psf	• First Floor: 100 psf • Second Floor: 100 psf • Third Floor: 100 psf	*ASCE 7-05 Chapter 4, Table 4-1*
L_r	20 psf	20 psf	*ASCE 7-05 Chapter 4, Table 4-1*

S	40 psf	40 psf	*ASCE 7-05 Chapter 7* (Procedure can be seen in Appendix C)
R	not considered, less than snow load	not considered, less than snow load	*ASCE 7-05 Chapters 8 and 10*
E	• First Floor: 29.56 kips • Second Floor: 21.11 kips	• Second Floor: 22.2 kips • Third Floor: 54.2 kips • Roof: 30.3 kips	*ASCE 7-05 Chapters 11 and 12* (Procedure can be seen in Appendix C)
W	• First Floor: 24 kips • Second Floor: 8 kips	• Second Floor: 30 kips • Third Floor: 20 kips • Roof: 10 kips	*ASCE 7-05 Chapter 6* (Procedure can be seen in Appendix C)

4.3 Structural Frame Design

There are two structural systems for every building. These systems can share the same members but serve to resist different loads. Gravity framing resists the loads in the direction of gravity. The lateral system resists the load of lateral forces and stops the building from moving laterally, also known as building sway. The layout of the structural framing needs to allow for a load path for conveying the supported forces into the ground. The typical load path in a steel framed building follows the load going into the floor, which transfers the load into the beams. The load from the beams then goes into the girders, which in turn, transfer the load to the columns. Finally, the columns pass the loads into the footing, which transfers the loads into the soil. Also, specific fire resistance ratings were determined for code compliance and implemented in the structural planning. To accelerate the design process, the *Steel Construction Manual* was used to size the steel members (American Institute of Steel Construction, 2013).

4.3.1 Braced Frame Design

For this project, a braced frame was used as the lateral force resisting system. Other types of lateral resisting systems include rigid frames and shear walls. The braced frame system was determined to provide the most important benefits to this building. Typically, rigid frames provide lateral support without causing additional members or walls to be placed; however, they are more expensive because they require a large increase in member size to achieve the necessary lateral resistance. Shear walls are more affordable but they add additional barriers in the floor plan, and they require large amounts of detailing for openings such as doors (Richard, 2008). In this case, the lateral frame cuts through both the Administration and Student buildings on diagonals. Flow through the interior space requires a large number of openings in the wall. Therefore, it was determined that a braced frame would be less expensive than rigid frames, but would allow for openings for doors and windows without requiring the detailing of shear walls. A typical braced frame configuration can be seen in Figure 24.

Figure 24: Example of a braced frame lateral system
http://www.stevenyoung.co.nz/index.php?option=com_content&task=view&id=236&Itemid=16

Braced frames help maintain the configuration of the columns and beams under lateral forces from wind and earthquake loads. The braces also provide additional stiffness. The braced frame restrains the building from displacing significantly in the lateral direction. Each member of the braced frame is a member of both the lateral and gravity systems. As a result, every member of this lateral system was designed for combined bending and axial loads. The members were also sized to provide enough stiffness so that the building meets the lateral displacement criteria.

Due to the unique configuration of the braced frame in the Gateway Campus Center, it became essential to understand and control the braced frame response at an early design stage. To understand the reaction of the braced frame to lateral loads, the response of the braced frame for the Student building was the focus for initial studies. Since both buildings' lateral systems share the same basic configuration they will respond in essentially the same way. However, since the Student building is larger, both in terms of height and mass, the lateral loads are larger than those for the Administration building. Therefore, the response of the Student building will more clearly show the problems associated with this unique braced frame configuration. The original placement of the braced frame of the Student building can be seen in red, in Figure 25.

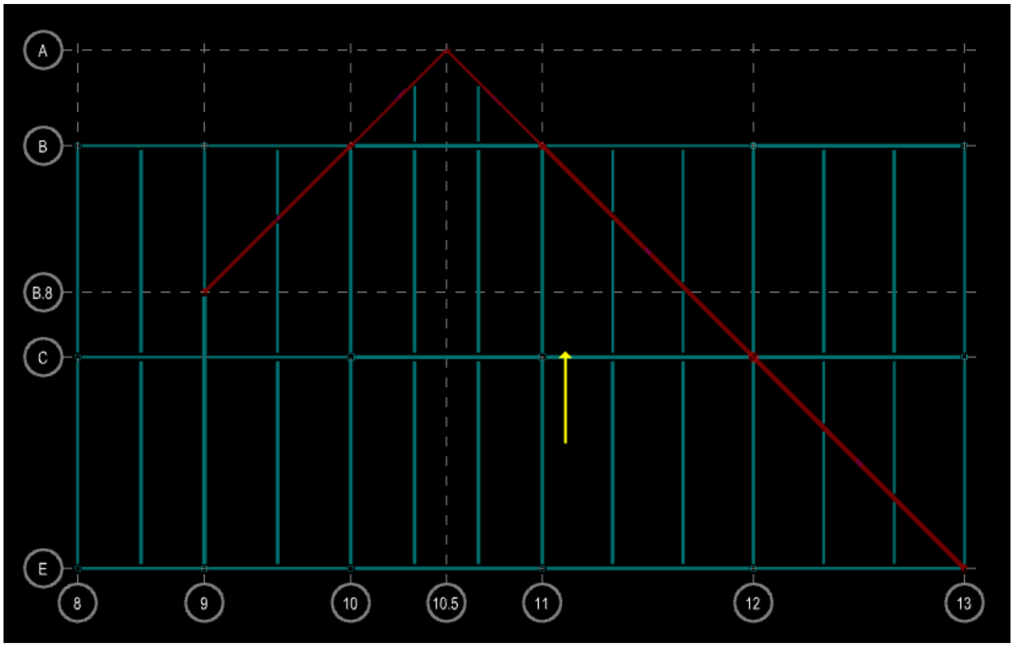

Figure 25: Original braced frame configuration, shown in red, and the Location of the force causing the worst response, shown as the yellow arrow

To explore the building response and calculate the forces in the braces, Ram Structural Systems, a program made by the company Bentley, was used. Ram Structural Systems was selected because it allowed quick and easy analysis of the indeterminate system. The building uses a rigid diaphragm floor system. This means that when the building sways, the floor retains its shape. The rigid diaphragm causes all the structural members of the lateral system to deflect by the same amount. As a result, the percentage of the total lateral force each member of the lateral system experiences is proportional to its stiffness compared to the overall stiffness of the system. Therefore, whenever a member's stiffness is adjusted all the loading in the system will be reapportioned. Ram Structural Systems was utilized to avoid manual recalculations of the force distribution as member sizes were changed.

The building was modeled approximately in Ram Modeler. This model included the brace wall, a rigid diaphragm created by the floor slabs, and rough placement of a few other members required to get the software to function properly. The lateral loads found in Section 4.2 were input into Ram Frame, and the building's response was examined. Ram Frame was then used to determine the forces in each member of the lateral system.

The original configuration of the frame produced unacceptable deflections and member sizes. The lateral forces were simplified for each floor as one concentrated load acting at the center of mass of the floor. However, according to *ASCE 7-05, Section 12.8.4.2,* to account for accidental torsion this force was applied at an eccentricity to the center of mass. The distance is specified as five percent of the building length perpendicular to the direction of the force applied. The location of the lateral force that causes the worst response was then used as the design case. Figure 25 shows the location of the force that produces the worst response. Since the braced frame rotates around column A-10.5, the eccentric force caused the braced frame to rotate dramatically, which can be seen in Figure 26.

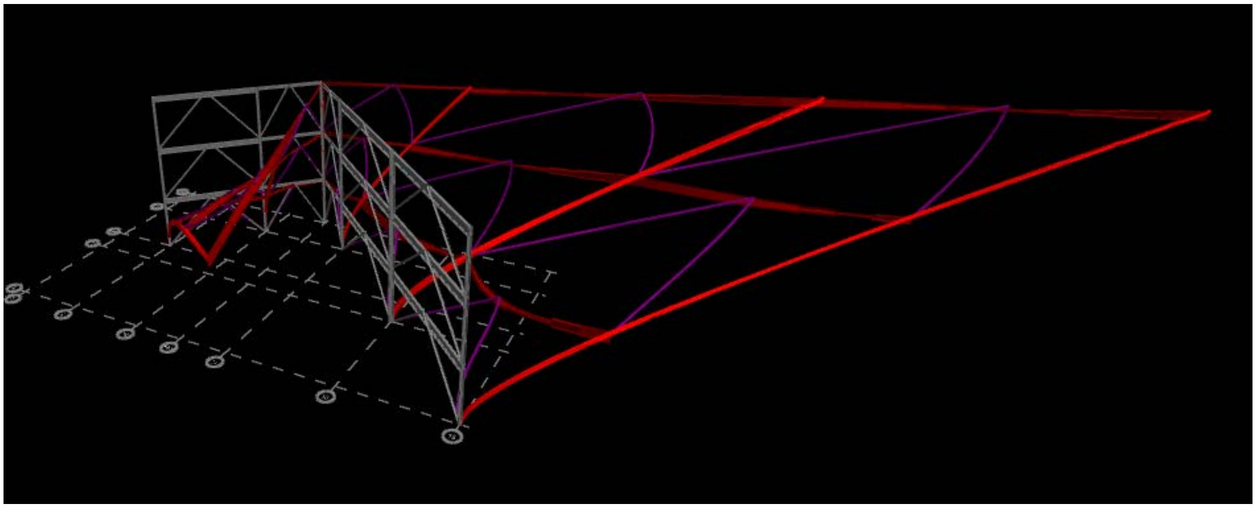

Figure 26: Most critical deflection case for the original braced frame configuration of the Student building. The Original shape is shown in gray; the deflected shape is shown in red and purple. Deflections are shown with a 20 scale factor.

Reducing the structural response to torsion was vital to the design of the building. The solution to this problem was to add another brace along gridline 13. This extra brace moved the center of stiffness of the lateral system towards gridline 13, dramatically reducing the torsion effect experienced. However, after coordination with the architectural system, it was determined that an additional brace could not be placed on this gridline due to interference with the large overhead door of the loading dock. The additional brace was then moved to gridline E, as shown in Figure 27, to address this coordination issue. The new configuration was implemented in Ram Frame, and provided successful results, shown in Figure 28. Once this new configuration was selected, the design forces for each member were obtained from Ram. Using *Steel Construction Manual, Part 6*, appropriate member sizes were established to resist the combined axial and bending forces (American Institute of Steel Construction, 2013). After these members were sized, they were input into the Ram Frame model, and the computed building sway was compared to the limit provided in *ASCE 7-05, Table 12.12-1*. If the building sway was too large, the stiffnesses of the members were increased and the process was repeated (American Society of Civil Engineers, 2006). This process was also used for the Administration building with similar results, as predicted.

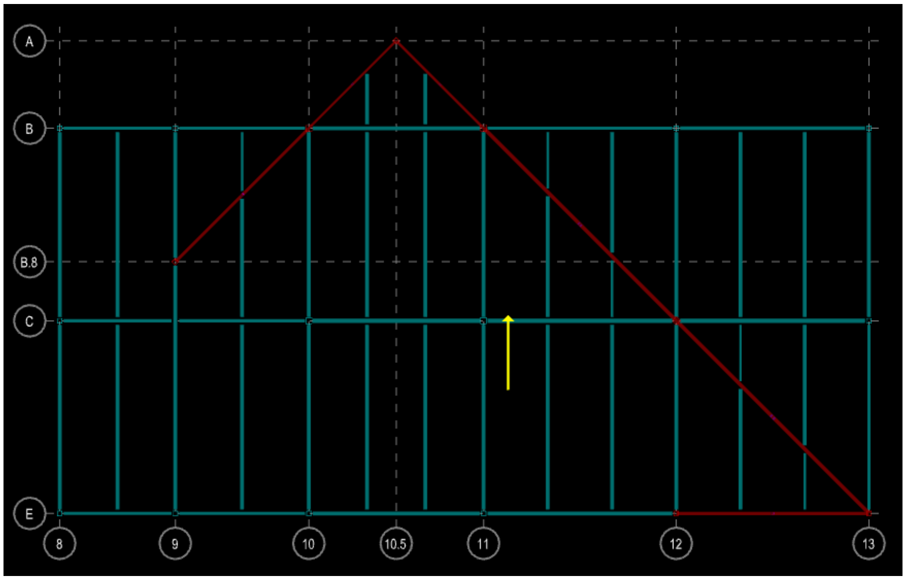

Figure 27: New braced frame configuration, shown in red, and the location of the force causing the worst response, shown as the yellow arrow

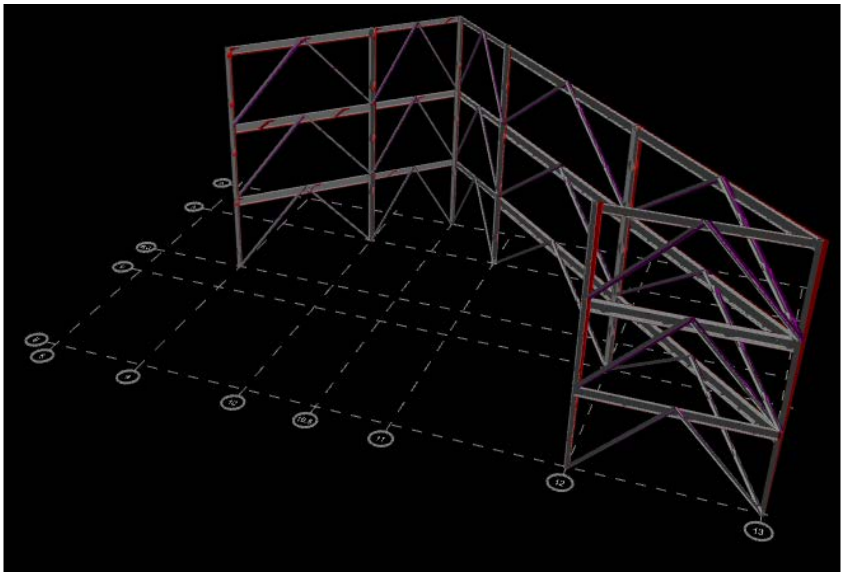

Figure 28: Most critical deflection case for the new braced frame configuration of the Student building. The Original shape is shown in gray; the deflected shape is shown in red and purple. Deflections are shown with a 20 scale factor.

4.3.2 Floor and Roof Deck Design

Typical floors in steel-framed buildings are constructed with concrete placed over a formed metal deck. This type of floor facilitates construction because it requires less temporary forming to support the wet concrete. This typical floor configuration can be seen in Figure 29. Floors that are supported directly by the underlying soils, also known as "on grade", are typically designed as a concrete slab with no metal decking. These slabs on grade require less temporary forming than elevated slabs because they are supported directly by the soil. Therefore, the benefits of using a metal deck are not as applicable as they are for elevated slabs. Since concrete has very low tensile strength, reinforcing bars or mesh are placed in the concrete to avoid cracking from bending and shrinkage of the concrete. The strength and stiffness properties of the floor slab determine the maximum spacing at which the supporting steel beams can be placed.

The floor systems for the two buildings were designed using these typical construction types. The elevated floors make use of a formed metal deck to decrease construction time. The floors at grade were designed to bear directly on the soil to avoid the need for unnecessary metal decking. The roof decks for the building will only be accessed for maintenance; therefore, they were designed without a concrete slab. This reduces the load at the roof level without reducing the usefulness of the area.

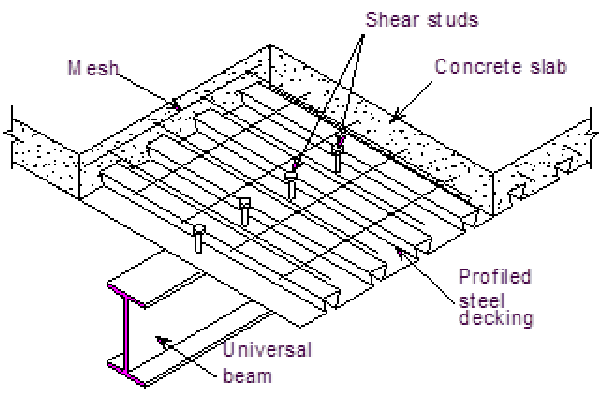

Figure 29: Typical concrete slab on metal deck configuration
http://www.steelconstruction.info/Design_of_composite_steel_deck_floors_for_fire

The floor and roof deck were designed using the *Vulcraft Steel Roof and Floor Deck* specification (Vulcraft, 2008). This is a specification published by the deck manufacturer, supplying the designer with structural properties of the decking. By determining the fire rating required and the maximum design load for the floor slab and roof deck, this specification was used to select the required decking sizes for the floor slab and roof. The weight and the maximum beam spacing for the selected flooring systems were also found from this specification and applied to the steel member design.

4.3.3 Beam Design

Steel beams are designed to sustain the maximum bending moment and shear force that the member will experience. Beams also must be designed so that they do not deflect by a significant amount. There are two typical types of steel beam constructions: composite and non-composite. Composite construction allows the steel members and the floor slab to work as one member. This is done by welding shear studs, shown in Figure 29, to the top of the steel section, through the troughs of the metal deck. The concrete is then placed over the shear studs. Once the concrete hardens, the floor slab and the steel beam move and bend together, allowing for increased strength capacity and smaller steel beams. However, the drawback of this approach is that it adds construction time and cost due to the need to weld each shear stud to the top of each beam. Composite action can either be designed as full composite or partial composite. Full composite has increased capacity but requires more shear studs. In some cases, full composite designs cause members to have excess capacity. In these instances, it is more economical to use partial composite beams.

Another decision for designing a composite beam is the type of construction used, shored or unshored. Shored construction relies on temporary supports to add extra capacity to the steel beams before the placing of the concrete. When the concrete hardens and can begin carrying loads, the supports are removed and the composite action is allowed to begin. In unshored construction, the steel beams are designed to support the weight of the wet concrete without any additional support. Unshored construction therefore requires larger beams but avoids the construction costs for the installation and removal of shoring.

The structure was designed for partial composite, unshored construction. This allows for a balance between beam size and construction time. All of the beams were idealized as simple span members with a uniformly distributed load. This simple construction allowed the maximum moment, deflection, and shear values to be easily calculated. These values had to be calculated twice, once under construction loads and once under service loads. Simple construction also allowed the use of simple connection types described in Section 4.3.7, thereby decreasing the amount of detailing and construction time required for each connection.

The steel beams were first sized for unshored construction and then for composite action under service loads, those experienced construction. Construction loads included dead and live loads. The dead loads come from the weight of the beam itself as well as the weight of the metal floor deck. The live loads considered a construction live load, as well as the addition of wet concrete. Since the concrete is not yet hardened and not in a permanent state, it was treated as a live load. A 10% increase in concrete slab weight was also applied to account for ponding effects. Ponding is the phenomenon of the beams and decking deflecting in the center slightly during the placing of the concrete, causing more concrete to be required to produce a level slab surface. Maximum moment and shear were calculated, and *Steel Construction Manual, Table 3-2* was used to select a member size that satisfied these requirements. Once the member size was selected, the design loading was updated to include the new beam self-weight, and the process repeated until an adequate member size was found. Finally, the deflection of the member was checked to make sure it fell under the acceptable limit for construction of beam span/240 or 1 inch. A spreadsheet was created so that these calculations could be repeated many different times for different beam configurations. The spreadsheet used can be seen in Appendix D. According to the *Steel Construction Manual,* if the shear stud diameter is 2.5 times the flange thickness of the beam, the studs need to be welded directly over the web of the beam. This adds construction time and can make it difficult to fit the required studs on the beam. As a result, members that do not meet this requirement were avoided or these members were treated as non-composite members (American Institute of Steel Construction, 2013).

A few beams were not designed as composite beams due to the orientation of the metal deck at these locations. These beams are not parallel to any gridline; an example can be seen in Figure 30. These beams were only designed for the more severe loading case, always service loads in this project. However, under service loads the deflection criteria changes. The deflection due to half the live load needs to be limited to L/360 or 1 inch, and the deflection due to the combination of dead load plus half the live load is limited to L/240 (American Institute of Steel Construction, 2003).

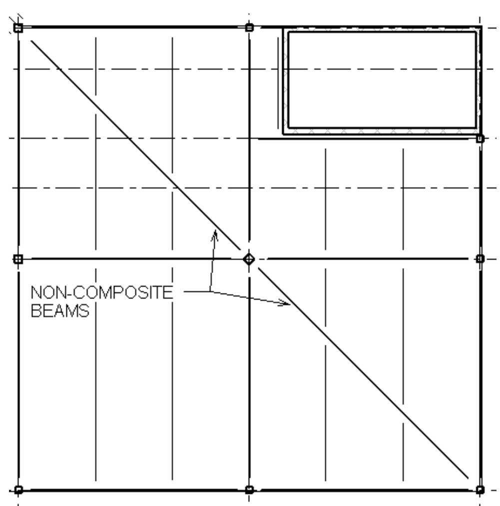

Figure 30: Example of beams that were designed as non-composite

Using the unshored construction sizes, beams were designed for service loads while taking advantage of partial composite action. The minimum composite action used for this project was 25%. This level was based on *Steel Construction Manual, Commentary I*. The goal was to use the lowest possible number of studs, but still satisfy the strength and deflection requirements. This decreases the construction cost and time for the building. The criteria for the size and length of the studs were found in the *Steel Construction Manual* page 16.1-90. The process described in the *Steel Construction Manual, Specification I* and *Steel Construction Manual, Commentary I,* along with *Steel Construction Manual, Tables 3-19, 3-20, and 3-21* were used to determine the number of studs required to fulfill both the strength and deflection requirements for the service load (American Institute of Steel Construction, 2013).

4.3.4 Girder Design

The design of the steel girders was very similar to the beams. Girders support the beams and thus carry more load. The girders also need to be large enough to allow for the beams to frame into them. Most of the girders were designed as simple span members with a uniformly distributed load as described above. However, due to the irregular geometry caused by the braced frame, the girders that are members of both the lateral and gravity systems were designed for gravity loads using concentrated loads at the location of each beam that they support. Once the loads were calculated, the design approach followed the process explained in the previous section for beams (American Institute of Steel Construction, 2013).

4.3.5 Vibration Guidelines

One of the major concerns for the structural design of this project was the vibrations associated with the third floor gym in the Student building. The gym in the Student building was moved to the third floor due to egress concerns and to allow for more floor area. Rhythmic forces caused by activities, such as aerobics and dancing, can cause uncomfortable and damaging vibrations. In order to control these vibrations, the *AISC Design Guide 11 Floor Vibrations Due to Human Activity* was used (Murray, 1997). This publication provides procedures to estimate the vibrations based on the activity being performed. It also provides acceptable limits of acceleration. To determine if the framing will cause concerns, the expected acceleration the bay will experience due to a rhythmic force is determined. This acceleration is then compared to the acceptable limit. If the framing considered does not satisfy the limit, member stiffnesses are increased in order to increase the frequency of the bay, thereby decreasing the likelihood of resonance.

The first step in exploring vibrations was to determine the expected rhythmic activities, as well as the appropriate acceleration limit for the system. Acceleration limit was based on considering all of the areas that will be affected by the vibrations. For this project, the controlling rhythmic force is aerobics. The areas of occupancy that will be affected by the rhythmic force are dining and weight lifting. Using Table 5.2 and 5.3 of *Floor Vibrations Due to Human Activity*, the acceleration limit, forcing frequency, weight of participants, and dynamic coefficient were all determined, and the values can be found in Table 3 below. Once these values were determined the vibration analysis was performed for one bay at a time. An excel spreadsheet was created to assist with these repetitive calculations, which can be seen in Appendix D.

Table 3: Values used for vibration parameters

Acceleration Limit, $\frac{a_0}{g}$	0.02
Forcing Frequency, f	First Harmonic = 2.75 Hz Second Harmonic = 5.5 Hz Third Harmonic = 8.25 Hz
Weight of Participants, w_p	2.5 psf
Dynamic Coefficient, α_i	First Harmonic = 1.5 Second Harmonic = 0.6 Third Harmonic = 0.1

The frequency of each bay was calculated from its elastic deformation using Equation 8. This was done by using the unfactored dead load of the floor, the w_p value above, the transformed moment of inertia for the member which includes the floor slab for composite members, and the tributary area of the member. The floor dead load includes the weight of the members, the concrete slab, and a maximum of four psf for mechanical and electrical systems. For composite beams the transformed moment of inertia was calculated based on the properties of the steel beam and the concrete slab. Once the deflections of all members were calculated, the fundamental natural frequency of the bay was obtained from the:

$$f_n = 0.18\sqrt{\frac{g}{\Delta_j+\Delta_g+\Delta_c}}_n \quad (8)$$

Where f_n is the fundamental natural frequency, g is the acceleration due to gravity, Δ_j is the maximum beam deflection, Δ_g is the maximum girder deflection, and Δ_c is the elastic shortening of the column. According to *AISC Design Guide 11 Floor Vibrations Due to Human Activity,* column shortening can typically be ignored for buildings less than six stories (Murray, 1997).

The next step was to determine the required frequency to prevent unacceptable vibrations for each harmonic of the rhythmic force. This required the application of the following equation for all three harmonics:

$$(f_n)_{req'd} = f\sqrt{1 + \frac{k}{\frac{a_0}{g}}\frac{\alpha_i w_p}{w_t}} \tag{9}$$

Where f, a_0/g, α_i, and w_p can be seen in Table 3 above, w_t is the weight of the floor, and k is a constant equal to 2 for aerobics. Once the required frequency for each harmonic was calculated, it was compared to the natural frequency of the bay calculated previously. If f_n is greater than or equal to $(f_n)_{req'd}$ for all harmonics, then the a/g value for each harmonic is calculated using:

$$\frac{a_p}{g} = \frac{1.3\alpha_i w_p/w_t}{\sqrt{\left[\left(\frac{f_n}{f}\right)^2 - 1\right]^2 + \left[\frac{2\beta f_n}{f}\right]^2}} \tag{10}$$

Where β is the damping ratio, which is equal to 0.06. The maximum acceleration experienced is then calculated using the a/g value from each harmonic and the equation:

$$a_m = \left[\sum a_i^{1.5}\right]^{1/1.5} \tag{11}$$

This a_m value, calculated in percentage of gravity, can then be compared to the maximum acceptable acceleration values given in Table 3. If the a_m value is larger than the acceptable limit then changes need to be made to the bay. The acceleration can be decreased by increasing the stiffness of the members or by adjusting the weight of the floor.

To help the vibration response of the gym floor, the use of lightweight concrete was explored for the floor slab. This change resulted in less load on the structural framing, causing the frequency of the bay to increase due to a decrease in Δ_j and Δ_g in Equation 8. The approximate cost of the lightweight concrete slab is $3.50 per square foot. Comparing this cost to the approximate cost of the normal weight concrete slab, $3.24 per square foot, shows an increase in cost. However, the lightweight concrete allows for better floor performance and smaller beam sizes, partially offsetting this increased cost. The lightweight concrete also allows for a thinner slab because lightweight concrete has a slightly better fire rating than normal weight concrete of the same thickness.

4.3.5.1 Irregular Bay Vibration Concerns

As shown in Figure 31, one of the bays supporting the gym floor has an irregular layout. Column C-9 was removed because it would have been in an unpleasant place in the lobby. However, this removal caused problems with vibrations. To determine the frequency of the irregular bay, an additional deflection value must be added to Equation 9 to capture the effect of the additional girder. This drastically decreases the bay frequency, requiring a tremendous increase in stiffness to reach the acceptable acceleration limit. However, the *AISC Design Guide 11 Floor Vibrations Due to Human Activity* does not directly address irregular bays. Therefore, other methods were explored to determine if this bay caused unacceptable accelerations (Murray, 1997).

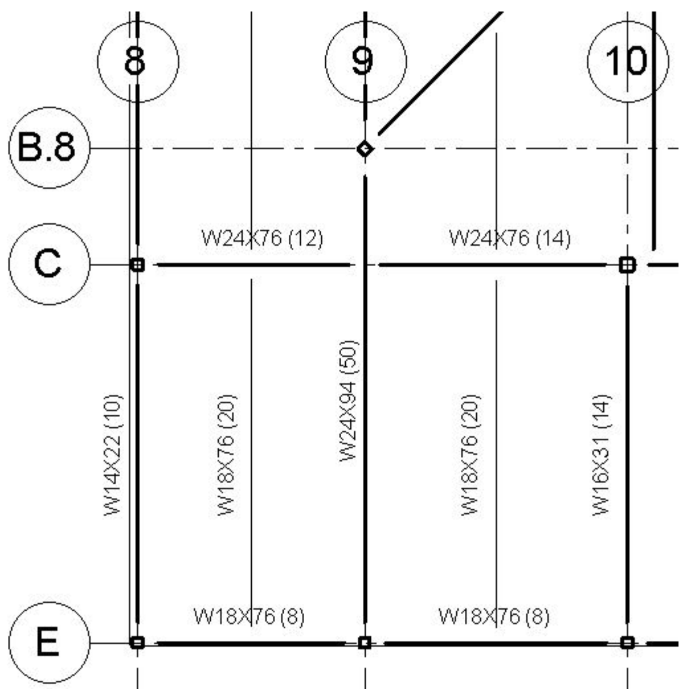

Figure 31: Irregular bay causing additional vibration concerns

Excessive accelerations are typically caused by the phenomenon of resonance. Resonance occurs when the frequency of vibration of the member in question matches the forcing frequency. A finite element program, Risa-3D, was used to determine the natural frequency for the bay in question. This was accomplished by modeling the bay in Risa-3D, then placing the loadings determined from *AISC Design Guide 11 Floor Vibrations Due to Human Activity* on the bay. The modal analysis feature of Risa-3D was applied, providing the modal shapes and natural frequencies of the bay. The first mode shape and the first five natural frequencies of the bay can be seen in Figure 32 and Table 4 respectively. As shown in Table 4, the lowest natural frequency of the bay was 10.487 Hz. This natural frequency was compared to the largest forcing frequency shown in Table 3, 8.25 Hz. Since the natural frequency of the bay is larger than that of the forcing frequency, it was determined that the bay would not be susceptible to resonance.

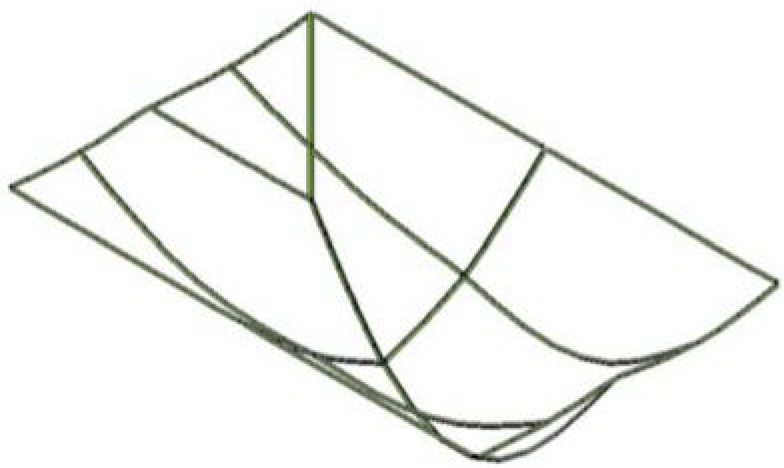

Figure 32: First mode shape of the irregular shaped bay from Risa-3D

Table 4: Natural frequency of the irregular shaped bay from Risa-3D

Mode	Frequency (Hz)	Period (Sec)
1	10.487	.095
2	10.529	.095
3	10.529	.095
4	12.742	.078
5	14.127	.071

To check the validity of this approach, the process was repeated for a bay that fits the requirements of *AISC Design Guide 11 Floor Vibrations Due to Human Activity*. The calculations described in Section 4.3.5 determined the natural frequency of the bay to be 10.53

Hz. The modal analysis using Risa-3D provided a natural frequency of 9.534 Hz. Therefore, the Risa-3D analysis was determined to be slightly conservative compared to the hand calculations. This comparison was used to conclude that the irregular bay would not cause vibration problems (Murray, 1997).

One of the other solutions explored for this vibration problem was the use of a “floating floor.” A floating floor uses very soft springs placed between the floor of the structure and the force causing the vibration concerns. These springs serve to reduce the vibration effect from rhythmic activities. Another benefit of a floating floor is that it can be placed at any point in a building’s lifespan and removed when it is no longer needed. The floating floor system will, however, add more load to the system (Murray, 1997). If unacceptable vibrations are experienced during the lifespan of this building, a floating floor could be placed on top of the existing floor. Due to the increased beam and girder size for the gym floor, the additional load of the floating floor system would not cause other concerns for the structural system.

4.3.6 Column Design

Columns transfer the load from the beams and girders to the foundations. Due to the phenomenon of buckling, the main property for a column’s capacity is unbraced length. A column is braced when a member restricts it from displacing in a given direction. Therefore, unbraced length is the distance between the members bracing the column. The larger the unbraced length, the less load a given column can support. The unbraced length value is multiplied by an adjustment factor, K, based on the connection types at the top and bottom of each column. Since all of the columns were assumed to be pinned at the top and bottom, the K value for all of the columns was one.

The maximum, design axial load for each column was found by multiplying the factored load, in psf, by the tributary area of the column. An example of column tributary area can be found in Appendix C. Table 4-4 of the *Steel Construction Manual*, was then consulted to determine a member that could support the calculated design load. The columns for this project were designed as square HSS members. This allows for increased flexibility when designing the connection of framing members into the columns and allows for simplified design as a result of the column stiffness properties being the same in both directions (American Institute of Steel Construction, 2013). The selected column sizes can be seen in the column schedule in Appendix K.

4.3.7 Connection Design

Due to the use of simple construction, the connections were designed simply to transfer the shear force from one member to another, without the concern of transferring moment. Typical connection types were used which allowed for design using the *Steel Construction Manual*. Double angle, single angle, and unstiffened seated connections were devised. These connection types allow for much of the work to be done in the steel shop, which helps reduce construction costs. A typical connection between a beam and a girder, as well as a girder to a column, was designed by determining the maximum shear value at each connection based on the beam and girder designs discussed in Section 4.3.3 and 4.3.4 respectively. These shear values were then used along with *Steel Construction Manual* Tables 10-1, 10-2, 10-5, 10-6, and 10-12 to calculate the required angle thickness, angle length, and required number of bolts or weld length. Another factor that was considered was the width of the column face available for connections. This factor caused the double angle connections to the columns to be unacceptable. After the length of both angles, the beam web, and the weld were all added, the overall width of the connection was larger than the workable face of the column. Therefore, single angle connections were used for connections to columns to reduce the workable face of the column required. A single angle connection to HSS6x6 columns could not be achieved due to the relatively narrow column face. An unstiffened seated connection was used for the connection to HSS6x6 columns because they require less column width. Typical connection details can be seen in Figure 33, Figure 34, Figure 35 and Figure 36.

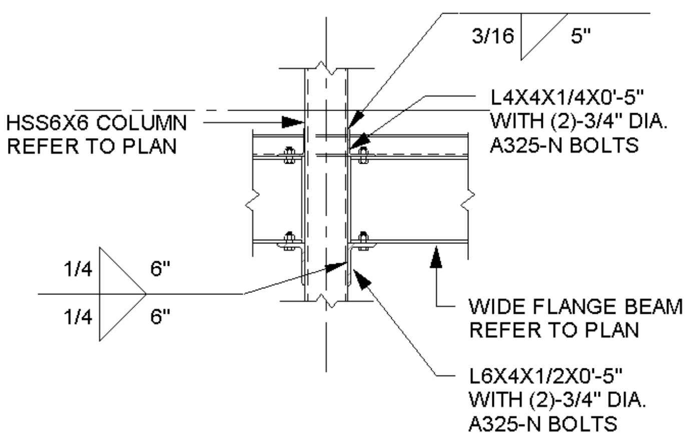

Figure 33: Typical unstiffened seated connection to an HSS6x6 column

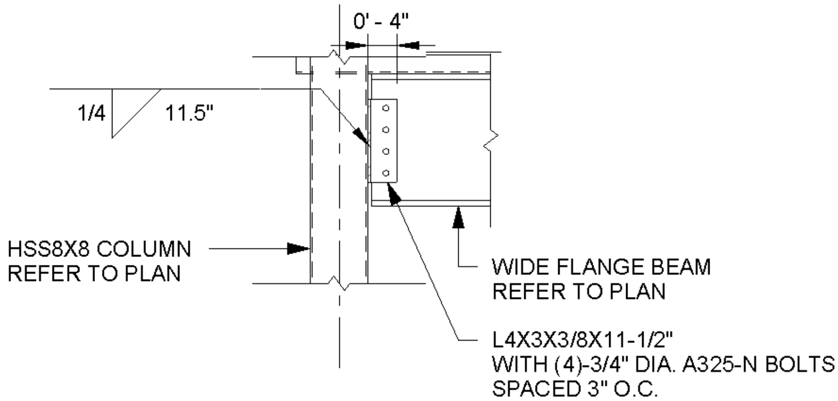

Figure 34: Typical single angle connection to an HSS8x8 Column

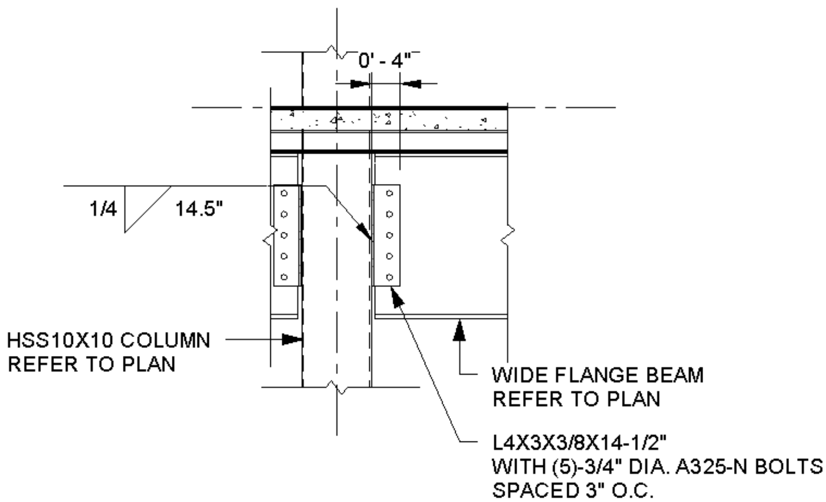

Figure 35: Typical single angle connection to an HSS10x10 column

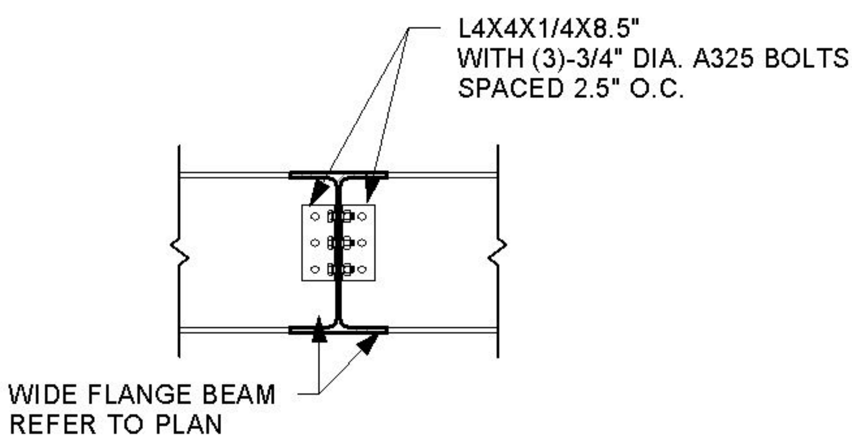

Figure 36: Typical double angle beam to girder connection

4.3.8 Base Plate Design

Base plates are steel plates welded to the base of steel columns. The base plate transfers the axial loads from the column into the foundation beneath. It increases the bearing area on the concrete foundation, allowing more concrete area to support a given amount of load.

Two base plates were designed: one that sits atop a concrete pier and one that sits directly on a spread footing. These two scenarios required a slightly different design process based on the ratio of the area of the supporting concrete to the area of the plate. The total area of the base plate was determined based on required concrete bearing area. The thickness of the base plate was determined based on the moment the base plate experiences. The design moment was calculated by treating the distance from the face of the column to the edge of the base plate as a cantilever. The thickness required to resist this moment defined the minimum thickness of the base plate. The two base plate designs can be seen in Figure 37 and Figure 38.

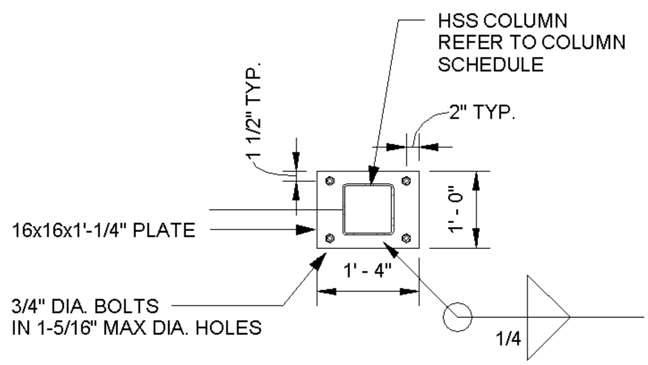

Figure 37: Base plate design used for all columns bearing on concrete piers

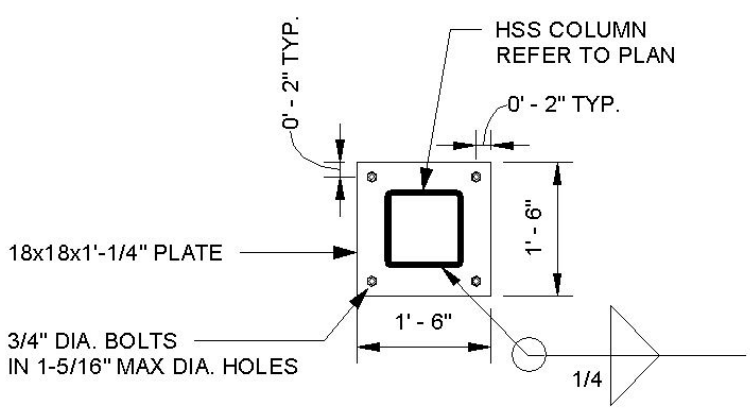

Figure 38: Base plate design used for all columns bearing on spread footings

4.4 Foundation Design

Foundations are typically placed underground and made of reinforced concrete, designed to support the load of the superstructure above them and transfer the load to the subsoil. Foundation design involves checking the strength of the concrete itself and exploring the reaction and strength of the soil that will be receiving the load from the foundation. Soil properties for this project were taken from a geotechnical report conducted on Prescott Street in 2005 by Maguire Group Inc.

One interesting observation from this geotechnical report is that the local bearing capacity for a shallow footing is 6000 psf; however, the bearing capacity for deep footings is only 3000 psf. Due to the basement of the Administration building, all the foundations for the Administration building were designed using the 3000 psf bearing capacity. The foundations for the Student building were designed using 6000 psf. Since concrete performs poorly in tension, embedding steel reinforcing bars is a useful tactic for producing additional strength and safety. Foundations are typically designed to sustain downward acting forces but in this case uplift forces must also be considered. The foundations supporting the brace wall will experience forces attempting to pull the foundation up out of the soil. Therefore, the foundations and the soil above them will need to be heavy enough to resist that uplift force.

Reinforced concrete is an inexpensive and durable material. It utilizes the high compressive strength of concrete along with the high tensile strength of steel. The foundation systems for the two buildings vary slightly. For both buildings, concrete piers transfer the force from the steel columns to spread footings beneath. According to *IBC 2009 Section 1809.5,* all permanent supports exposed to frost need to extend below the frost line of the locality. This included all foundations at the exterior of the building. The frost line was taken as four feet below grade for this project. As a result, the concrete piers were required to transfer the load from the columns to the spread footings located below the frost line. For foundations not exposed to frost, including interior foundations, the minimum footing depth below grade was set at only 12 inches. This allowed the column base plates to bear directly on the spread footings.

Due to the basement in the Administration building, the Administration and Student buildings required different design processes. As a result of the height and amount of soil retained by the basement walls of the Administration building, these walls were designed to sustain the lateral load of the soil. This required the basement wall and its wall footing to be designed together as a retaining wall. For the Student building, the foundation walls are non-bearing and are only necessary to reach the depth of the frost line. Beneath these walls, a strip footing was placed to distribute the small amount of load from these foundation walls to the soil.

4.4.1 Pier Design

The axial loads and moments determined by the brace wall and column designs described in Sections 4.3.1 and 4.3.6, respectively, were used for the pier design. Each pier must have sufficient strength to support the combined axial load and moment from the column. This was checked by dividing the design value of the axial load by the axial capacity of the pier and dividing the design moment by the bending capacity of the pier, shown in Equations 12 and 13 respectively. Published design aids were then consulted to determine the area of longitudinal

$$k_n = \frac{P_u}{\phi f'_c A_g} \tag{12}$$

$$R_n = \frac{M_u}{\phi f'_c A_g h} \tag{13}$$

reinforcing steel necessary to sustain these combined axial and bending loads (Nilson, 2009). A sufficient amount of reinforcing steel was then selected to satisfy this requirement. Transverse reinforcement was also defined to resist shrinkage and temperature cracking. The transverse reinforcement was determined based on spacing which is the minimum of 16 times the diameter of the longitudinal bars, 48 times the diameter of the transverse bars, and the least pier dimension. One pier design was acceptable for all locations. This pier can be seen in Figure 39.

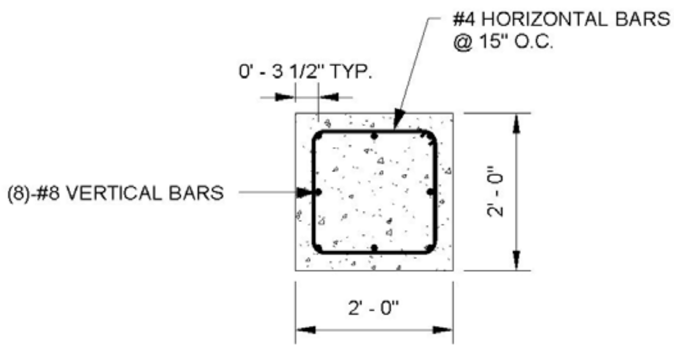

Figure 39: Pier used to transfer load from steel columns to deep spread footings

4.4.2 Spread Footing Design

Spread footings are placed beneath a steel column or concrete pier to increase the area of soil to which the axial load is applied. The required area of the spread footing was determined by dividing the unfactored column load by the effective bearing capacity of the soil. The unfactored load consists of the axial load of the column plus the weight of the pier, if applicable. The effective soil bearing pressure is the actual bearing pressure minus the weight in pounds per square foot of the concrete and soil above the base of the footing. Once the area of the footing was established, the thickness of the footing was determined based on strength requirements for shear, punching shear, and bending moment. Once the area and thickness were established, the amount of reinforcing was determined and the number of bars placed in each direction was selected. An Excel spreadsheet was created for spread footing design to facilitate repeated calculations. This spreadsheet can be seen in Appendix D. The resulting footing designs are summarized in Table 5.

Table 5: Summary of spread footing sizes and bar reinforcements used

FOOTING SCHEDULE		
TYPE	SIZE	REINFORCEMENT
F50	5'-0"x5'-0"x12"	(6)-#5 BOTTOM EACH WAY
F60	6'-0"x6'-0"x18"	(8)-#6 BOTTOM EACH WAY
F70	7'-0"x7'-0"x18"	(7)-#7 BOTTOM EACH WAY
F80	8'-0"x8'-0"x24"	(10)-#8 BOTTOM EACH WAY
F90	9'-0"x9'-0"x24"	(10)-#8 BOTTOM EACH WAY

4.4.3 Basement Wall Design

The foundation wall design was different for the two buildings. The Administration building has a basement which requires the height of the foundation wall to be 13 feet. Also, since there is soil on one side of the wall but not on the other, these walls were designed as cantilevered retaining walls with a height of 13 feet. These walls were designed to restrain the whole lateral soil load without being restrained at the top. This allows for decreased construction time as the floor on deck does not need to be cast prior to the backfilling. Also, due to the configuration of the Administration building the floor beams supporting the first floor bear directly in the foundation wall. This means that the walls need to be designed to support both the lateral force from the soil and the vertical force from the beams. Retaining walls are defined as three components, identified in Figure 40. The heel, toe, and stem work together to resist the failure modes shown in Figure 41. As a result of this interaction, a retaining wall is designed as one system.

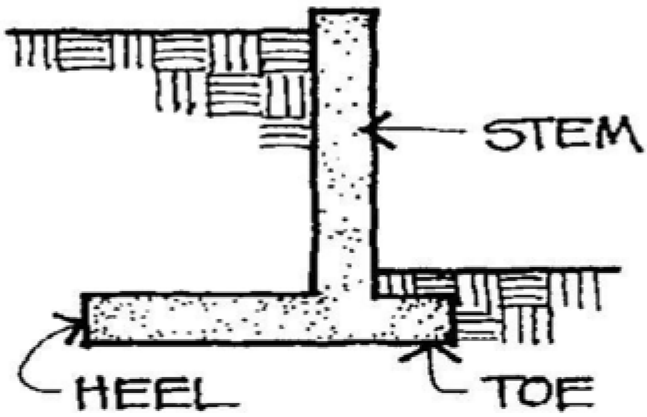

Figure 40: Components of a typical cantilevered retaining wall
https://www.studyblue.com/notes/note/n/arc-666-study-guide-2012-13-are/deck/9714156

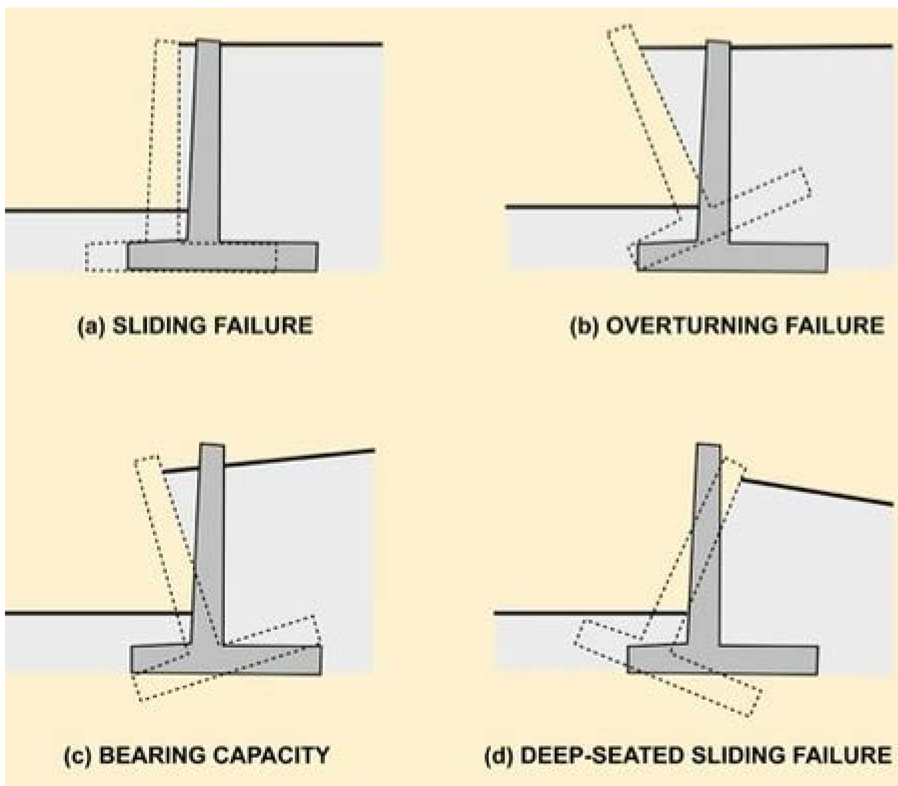

Figure 41: Typical failure modes for a cantilevered retaining wall
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4.4.4 Foundation Wall Design

The Student building does not have a basement, meaning the walls only need to extend approximately three feet below grade. These walls were designed to support a small load due to the exterior wall above. Also, the width of the foundation walls must be at least as wide as the supported wall above. The width of the foundation walls for the Student building was controlled by the width of the exterior wall above, 16 inches. The minimum ratio of longitudinal and transverse reinforcement was determined from *Building Code Requirements for Structural Concrete* as 0.0012 and 0.0020 respectively (American Concrete Institute, 2014). These values were used to select the appropriate size and spacing for the longitudinal and transverse reinforcement of the foundation wall.

4.4.5 Strip Footing Design

Strip footings are placed beneath wall and serve the same purpose as spread footings: they increase the bearing area and reduce the stresses within the supporting soil. As a result of the retaining wall being designed as one system, the Administration building does not require strip footings. Therefore, the only strip footings in this project are located beneath the foundation walls of the Student building. The strip footing design is very similar for that of the spread footing; however, during design only one foot of wall is examined to simplify the process. Since the foundation walls extend three feet below grade and the frost protection depth is four feet, the minimum strip footing thickness for this project was one foot. The typical strip footing used for the Student building can be seen in Figure 42.

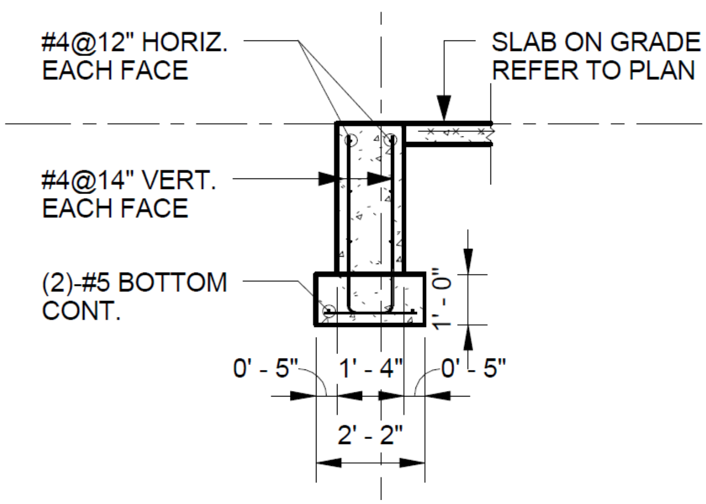

Figure 42: Foundation wall and strip footing detail for Student building

4.5 Structural Cost Analysis

After the structural design was completed, a cost estimate of the structural system was performed. The structural components of the building were divided into several categories. The Revit model was used to determine the quantity of material within each category. The average national cost per unit for each category was then taken from *RSMeans Building Construction*

Cost Data (Plotner, 2014). These national averages include materials, labor, overhead, and profit. *RSMeans Building Construction Cost Data* also provided location factors, which are used to adjust the national averages to better reflect the desired location. This is done by multiplying the national average by the specific location factor divided by 100. The total structural cost estimate can be seen in Table 6. This total corresponds to approximately $30.27 per square foot for both buildings. A typical cost per square foot estimate for the structural components of a steel framed building, was taken from *RSMeans Square Foot Costs* as $25.48 per square foot (RSMeans, 2010b).

The vibration concerns of the elevated gym caused an increase in the cost of the structural system. To reduce the acceleration of the floor due to rhythmic forces, the beams and girders for the third floor of the Student building were increased, increasing the total cost for the project. A more detailed cost analysis along with the Worcester location factors can be seen in Appendix E.

Table 6: Total structural cost estimate, adjusted using Worcester location factor

Component	Cost Including (O&P)	
Columns	$	86,287.71
Beams, Girders, & Braces	$	338,211.59
Shear Studs	$	6,134.92
Concrete Piers (Reinforcing)	$	17,115.54
Retaining Wall and Footing (Reinforcing)	$	107,058.99
Frost Wall (Reinforcing)	$	24,604.82
Wall Footings (Reinforcing)	$	9,356.10
Under 5 C.Y. Spread Footings (Reinforcing)	$	35,959.67
Over 5 C.Y. Spread Footings (Reinforcing)	$	6,584.40
Slab on Grade (No Reinforcing)	$	36,790.71
Normal Weight Elevated Slab (No Reinforcing)	$	26,622.89
Lightweight Elevated Slab (No Reinforcing)	$	38,719.12
3" Deep 20 Gauge Composite Deck	$	64,113.97
3" Deep 20 Gauge Roof Deck	$	30,103.30
WWF 6X6-W2.9XW2.9	$	21,619.81
Total =	$	849,283.56

5.0 Fire Safety Design

Fire safety design is a very important part of the entire building design. Fire safety design is one of the driving factors in defining a number of building elements, such as the width of stairs and doors, the amount of exits needed, and the location of stairs for travel distance purposes. Specific egress requirements include identifying the occupancy and use classification of the different sections of the building, calculating the occupant load, which then allows for the calculation of the number of exits and their width, and then determining if the common path of travel and the travel distance meets code requirements. These specifications are factored by if a building is sprinklered or not. A sprinklered building has less strict requirements than a non-sprinklered building due to the increased evacuation time occupant have.

5.1 Egress analysis

The architectural design must meet egress analysis requirements found in the *International Building Code.* Some references can be made in *NFPA 101 Life Safety* where applicable.

5.1.1 Occupancy and Use Classification

Because the tower closes off all levels between the Administration and Student buildings except for the ground floor, the entire facility was split into two sections for analysis. Once the program and layout of the Student and Administration buildings were determined, methods of egress were calculated for each building to meet code. Per the *International Building Code* Chapter Three, Occupancy and Use Classification, the main occupancy type of this building is assembly, with incidental, storage, mercantile, and business use areas. Assembly type spaces are the most restrictive in regards to egress requirements. Although the Gateway Campus Center was analyzed as two buildings, it also meets the egress requirements when considered as one building.

5.1.2 Occupant Load

When analyzing egress, the square footage of each room and its occupancy type need to be determined to calculate the occupant load. The square footage was taken from the rooms pre-designed in the architectural layouts. Once the room areas were known, Table 1004.1.1 in the *IBC* was used to determine the floor area per occupant allowed. This table provides the maximum floor area allowances dependent on the function of the particular space. The actual floor area was then divided by the table values for each room/space to determine the occupant load for that area. For example, if there is an exercise room that is 1000sqft, it can be seen that the floor area per occupant is 50 net. This would mean that the calculated occupant load for that area would be 20 people.

TABLE 1004.1.1 MAXIMUM FLOOR AREA ALLOWANCES I

FUNCTION OF SPACE	FLOOR AREA IN SQ. FT. PER OCCUPANT
Accessory storage areas, mechanical equipment room	300 gross
Agricultural building	300 gross
Aircraft hangars	500 gross
Airport terminal	
Baggage claim	20 gross
Baggage handling	300 gross
Concourse	100 gross
Waiting areas	15 gross
Assembly	
Gaming floors (keno, slots, etc.)	11 gross
Assembly with fixed seats	See Section 1004.
Assembly without fixed seats	
Concentrated (chairs only-not fixed)	7 net
Standing space	5 net
Unconcentrated (tables and chairs)	15 net
Bowling centers, allow 5 persons for each lane including 15 feet of runway, and for additional areas	7 net
Business areas	100 gross
Courtrooms-other than fixed seating areas	40 net
Day care	35 net
Dormitories	50 gross
Educational	
Classroom area	20 net
Shops and other vocational room areas	50 net
Exercise rooms	50 gross
H-5 Fabrication and manufacturing areas	200 gross
Industrial areas	100 gross
Institutional areas	
Inpatient treatment areas	240 gross
Outpatient areas	100 gross
Sleeping areas	120 gross
Kitchens, commercial	200 gross
Library	
Reading rooms	50 net
Stack area	100 gross
Locker rooms	50 gross
Mercantile	
Areas on other floors	60 gross
Basement and grade floor areas	30 gross
Storage, stock, shipping areas	300 gross
Parking garages	200 gross
Residential	200 gross
Skating rinks, swimming pools	
Rink and pool	50 gross
Decks	15 gross
Stages and platforms	15 net
Warehouses	500 gross

Figure 43: Maximum Floor Area Allowances

All of the occupant loads for a specific floor were added together to determine the total occupant load for the floor. This was done to determine the required number of exits needed for the floor. The minimum number of exits for occupant loads were determined using Table 1021.1 in the *IBC*. For both the Student and Administration buildings, it was calculated that each building needs at least two exits per floor. The maximum occupant load was the Administration building basement, at 305 people, which is less than the 500 person limit for two exits.

TABLE 1021.1 MINIMUM NUMBER OF EXITS FOR OCCUPANT LOAD

OCCUPANT LOAD (persons per story)	MINIMUM NUMBER OF EXITS (per story)
1-500	2
501-1,000	3
More than 1,000	4

Figure 44: Minimum Number of Exits for Occupant Load

When determining exits, those on floors other than the ground level incorporated the main stairs as an available exit. This is allowed as long as each exit accounts for half of the level's occupant's load, as described in 1005.1. As per 1004.4 in the *IBC*, the exit requirements for the building were determined on a floor-by-floor basis in regards to the occupant load. This is permissible as long as the exit capacity does not decrease in the direction of egress travel.

	FLOOR	BUILDING USE	IBC CODE CLASSIFICATION	FLOOR AREA PER OCCUPANT	FLOOR AREA (SQFT)	OCCUPANT LOAD	TOTAL OCCUPANT LOAD	REQUIRED # OF EXITS
ADMINISTRATION	Basement	Fire Pump Room	Incidental	300	131	0.44	304.09	2
		Elevator Control Room			282	0.94		
		Outdoor Storage	Storage	300	97	0.32		
		Lounge/Seating	Assembly	7	2079	297		
		Tech Suites	Business	100	539	5.39		
	1	Store Storage/loading	Storage	300	259	0.86	264.43	2
		Kitchen Storage			189	0.63		
		Convienience Store	Mercantile	30	608	20.27		
		Coffee Bar			273	9.1		
		Lobby/Seating	Assembly	7	1635	233.57		
	2	Janitor's Closet	Storage	300	133	0.44	216.58	2
		Resource Area	Business	100	46	0.46		
		Conference Rooms			510	5.1		
		Offices			472	4.72		
		Lounge/Seating	Assembly	7	1441	205.86		
STUDENT	1	Loading Dock/Storage	Storage	300	392	1.31	299.52	2
		Elevator Control Room	Incidental	300	103	0.34		
		Water Pump Room			117	0.39		
		Lobby/Seating	Assembly	7	1234	176.29		
		Food Seating/Court	Assembly	15	1789	119.27		
		Kitchen	Incidental	200	386	1.93		
	2	Tech Suites	Business	100	909	9.09	296.52	2
		Seating/Gaming	Assembly	7	2012	287.43		
	3	Gym/Dance Studio	Assembly	50	3438	68.76	80.46	2
		Locker Rooms			585	11.70		

Figure 45: Occupant Load and Required Number of Exits per Section per Floor

5.1.3 Egress Width

Once the occupant load was established per level, the egress width was determined. Exit widths were calculated by exit allowances of 0.2in/person for exit doors, and 0.3in/person for exit stairs, as per IBC 1005.1. The exit widths, rounded to the nearest inch, were determined by multiplying the total occupant load per floor by the exit allowance. When the exit widths were calculated, the available exit doors/stairs that met the widths defined the exit capacity of the floor. The exit capacity always needs to be greater than the occupant load for the floor.

For the Gateway Campus Center design, the Administration building had an exit door requirement of 36 inches and an exit stair requirement of 44 inches. The basement level had three exit doors and one exit stair, since two of the exit doors led to the outdoor terrace. The Student building had an exit door requirement of 36 inches and an exit stair requirement of 45 inches. The amount of exits and the total exit capacity per floor per building can be found in Table 7.

For both the Student and Administration buildings, the main stairs needed to be at a minimum of the exit stair width for that building section because they are a part of the exit system. The tower has five exit doors, which is more than enough for the amount of square feet it covers, as well as for the connecting Student Building. The tower is considered to be a part of the Student Building, so the exit doors that are associated with it are a part of the Student Building egress design.

Table 7: Exit Capacity per Section per Floor

	FLOOR	TOTAL OCCUPANT LOAD	EXIT ALLOWANCE (IN/PERSON)	EXIT WIDTH (IN)	EXIT CAPACITY
ADMINISTRATION	Basement	305	0.2 (Door)	36x3	540
			0.3 (Stair)	44x2	294
	1	265	0.2 (Door)	36x4	720
	2	217	0.2 (Door)	36	180
			0.3 (Stair)	44x2	294
STUDENT	1	300	0.2 (Door)	36X4	720
	2	297	0.2 (Door)	36	180
			0.3 (Stair)	45x2	300
	3	81	0.2 (Door)	36	180
			0.3 (Stair)	45x2	300

Initial designs considered the outdoor terrace of the Administration building to be an exit. Due to limited feasibility of site work and cost, this was changed to not be considered an exit. Because the outdoor terrace did not go to ground level, people would need to reenter the building, forcing the egress conditions of the Administration to accommodate this need. To satisfy the 305-person basement occupant load, both stair treads needed to be increased by two inches. This increased the exit stair width by four inches, but the length did not change due to the landings being of sufficient width. The updated exit capacity can be seen in Table 8.

Table 8: Updated Exit Capacity per Section per Floor

	FLOOR	TOTAL OCCUPANT LOAD	EXIT ALLOWANCE (IN/PERSON)	EXIT WIDTH (IN)	EXIT CAPACITY
ADMINISTRATION	Basement	305	0.3 (Stair)	46x2	307
	1	265	0.2 (Door)	36x4	720
	2	217	0.2 (Door)	36	180
			0.3 (Stair)	46x2	307
STUDENT	1	300	0.2 (Door)	36X4	720
	2	297	0.2 (Door)	36	180
			0.3 (Stair)	45x2	300
	3	81	0.2 (Door)	36	180
			0.3 (Stair)	45x2	300

In initial design phases, the Student building had the gym placed on the second floor and the recreational/game area on the third floor. Because the third level had the highest square footage, the gaming center had a large exit capacity. In this case, if the gaming floor was kept on the third level, the exit stair would have needed to be 56 inches in order to meet the elevated occupant load amount, a very large width for an exit stair. To address this concern, more tech suites were proposed on the floor to accommodate for more business occupancy and less assembly occupancy, decreasing the occupant load. Still, the occupant load did not decrease enough to make a significant reduction in the exit stair width. Due to this, the gym was moved to the third level because of a much smaller floor area per occupant multiplier, and the gaming level was moved to the smaller second floor. This allowed for the exit stair in the student section of the building to be 45 inches wide. Although the gym being moved from the second to the third floor was beneficial in regards to egress analysis, it presented an issue with vibration. Due to this, the floor was changed from normal weight to lightweight concrete.

The following figures illustrate the egress plans incorporated in each building. These plans include the representations of light blue egress stairs, dark blue egress doors, and orange directional arrows.

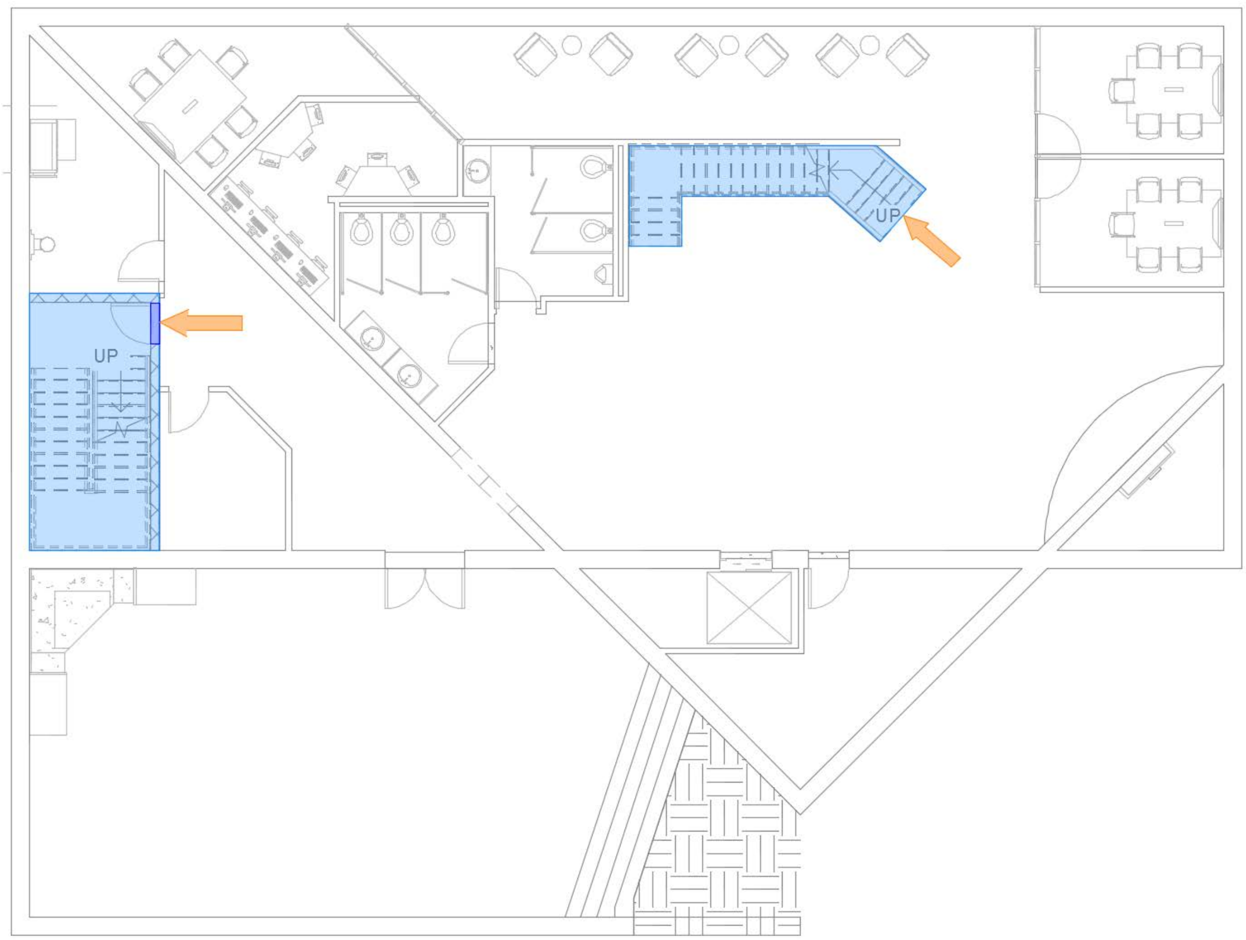

Figure 46: Administration Building Basement Egress Plan

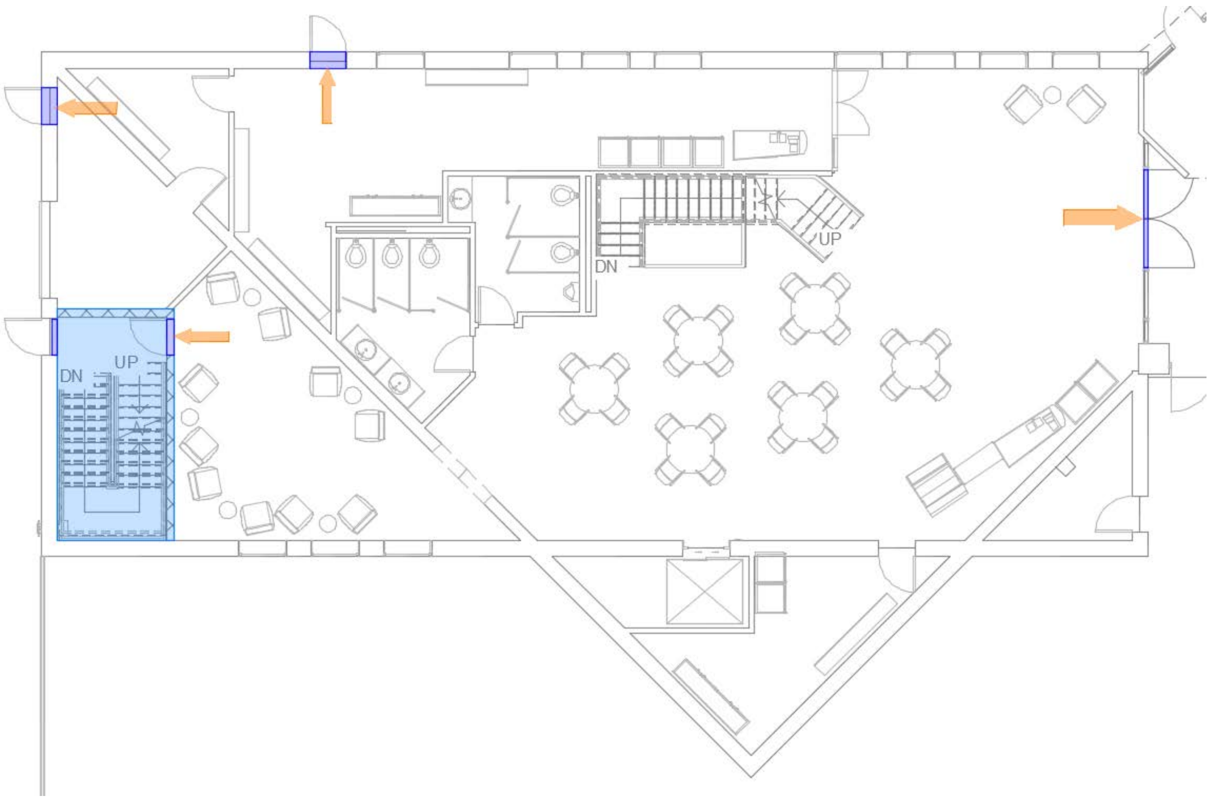

Figure 47: Administration Building First Floor Egress Plan

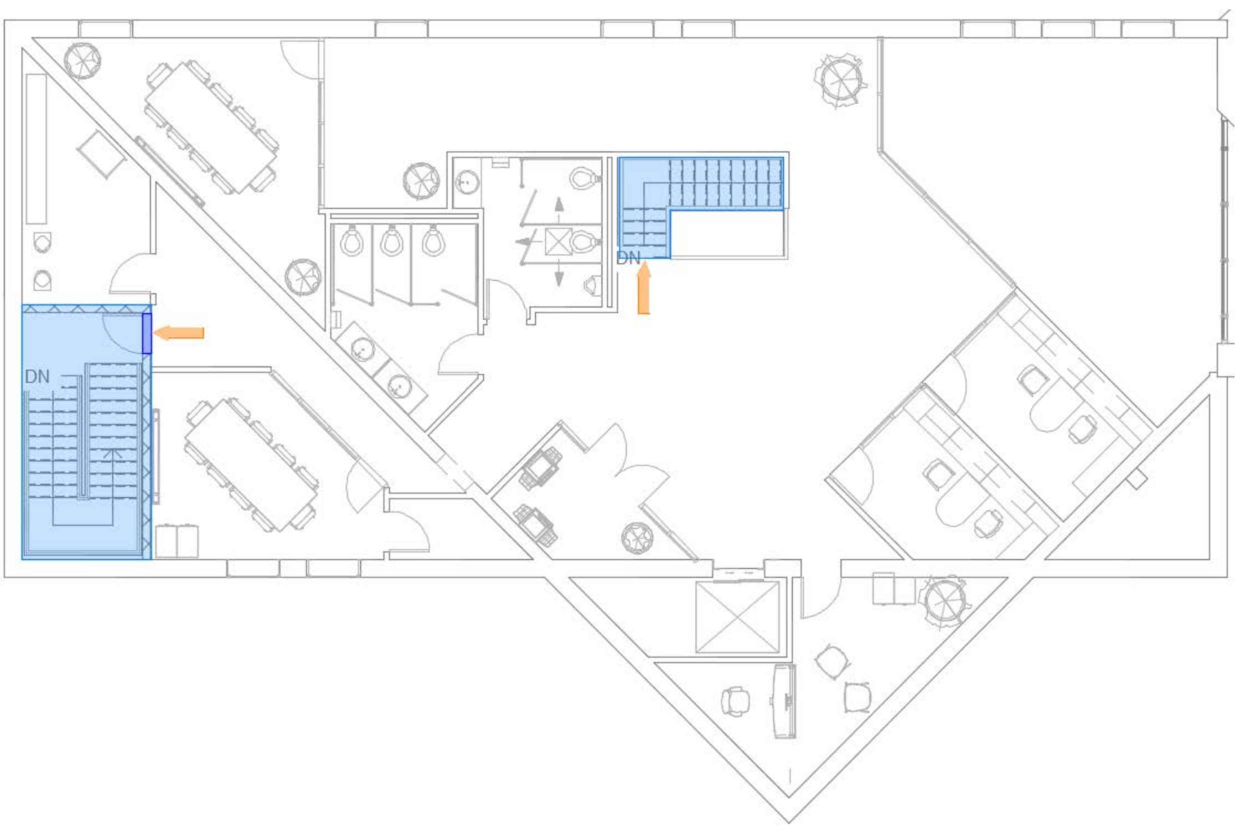

Figure 48: Administration Building Second Floor Egress Plan

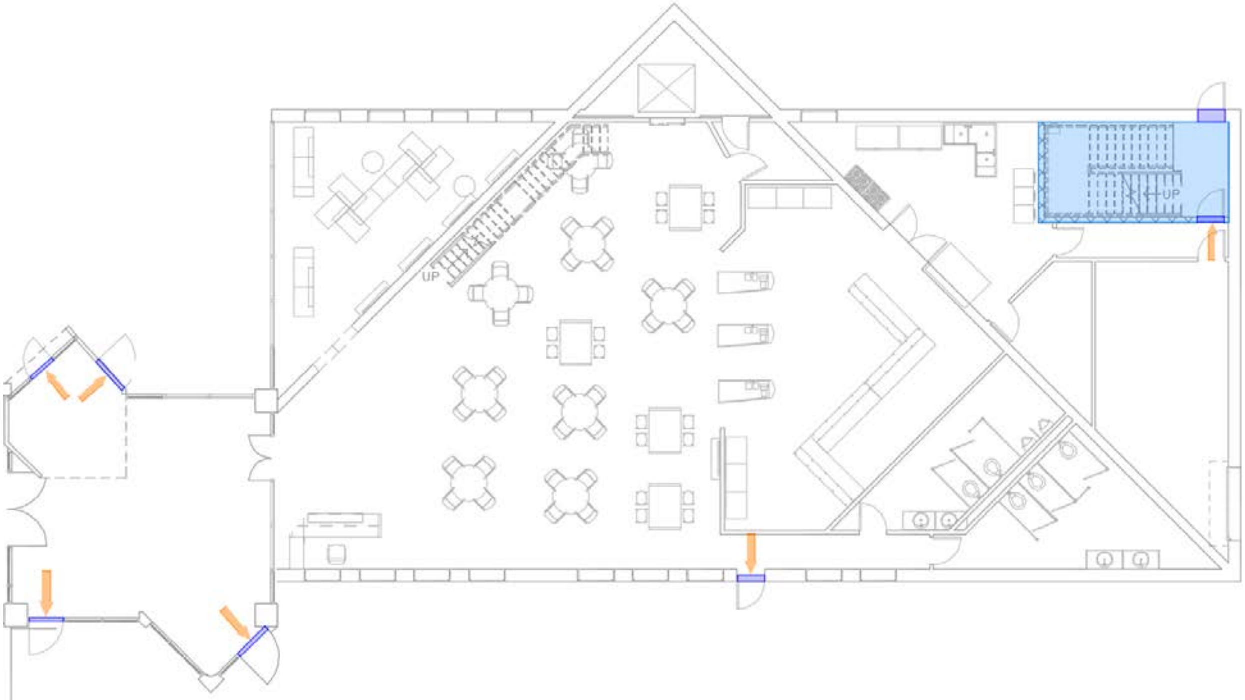

Figure 49: Student Building First Floor Egress Plan

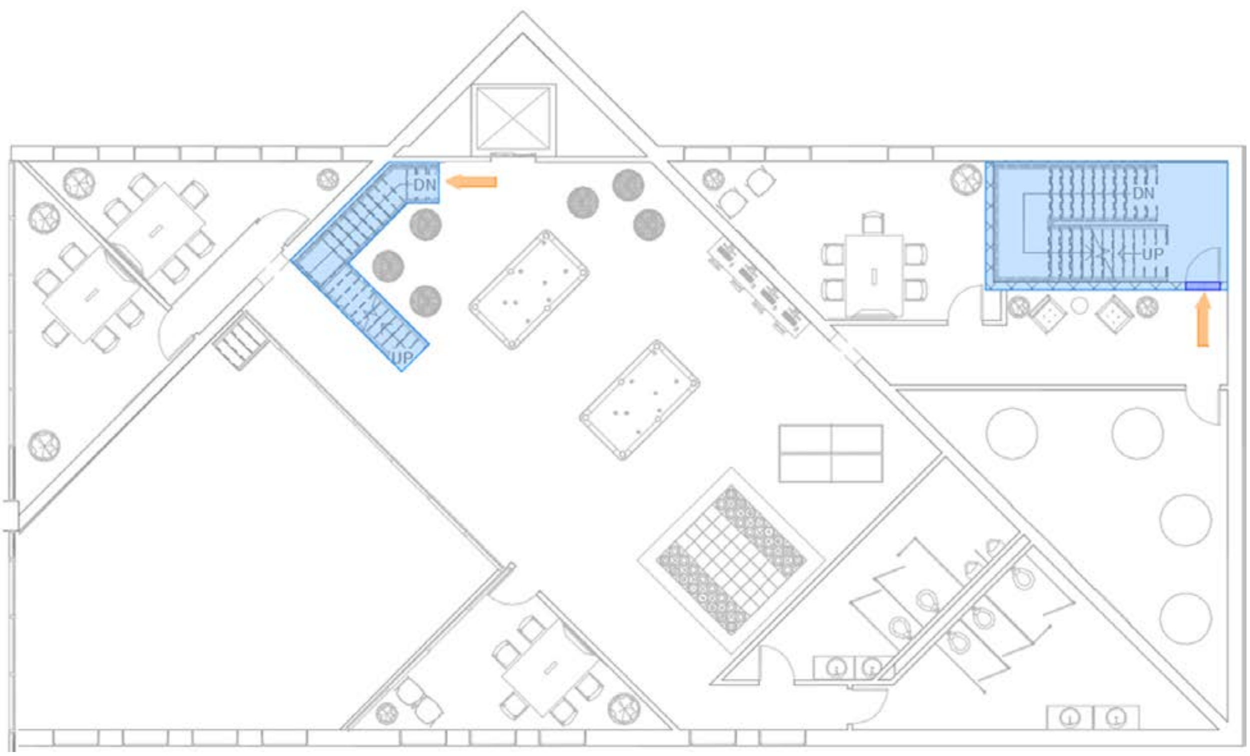

Figure 50: Student Building Second Floor Egress Plan

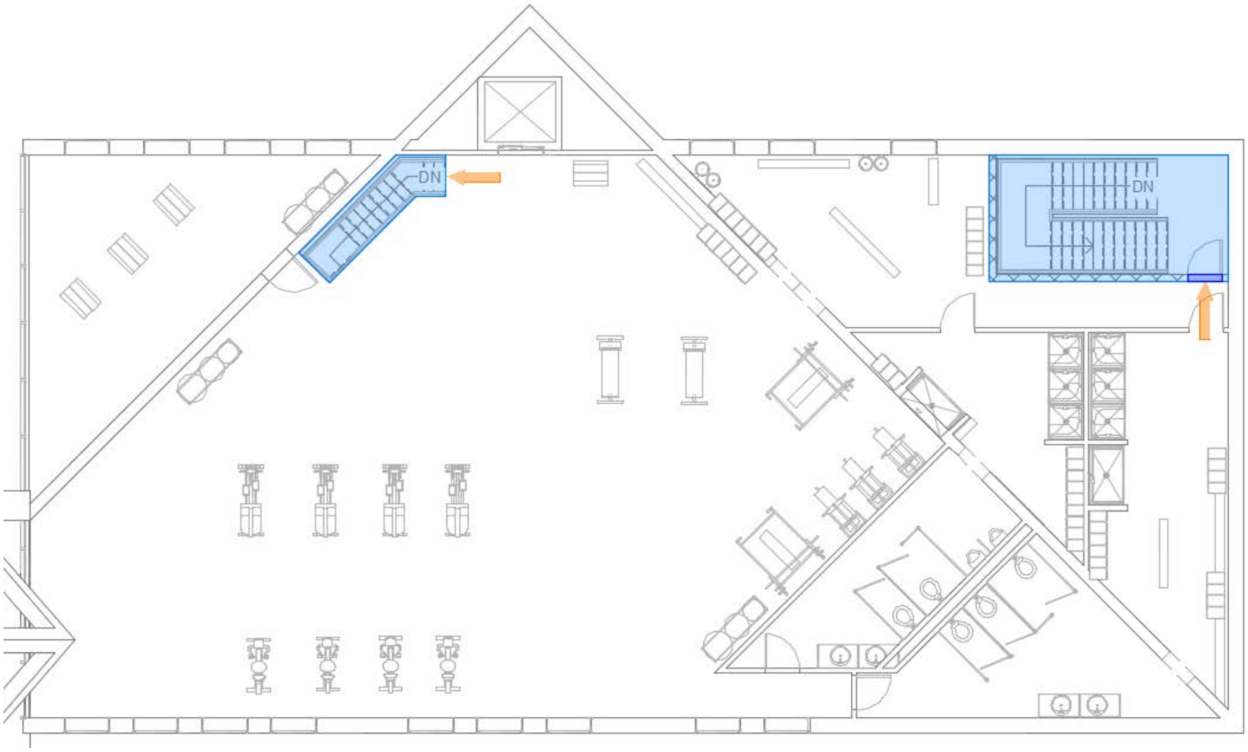

Figure 51: Student Building Third Floor Egress Plan

5.1.4 Horizontal Exit

Because the structure was broken up into two separate buildings in regards to egress systems, and one building typically is not allowed to have its egress system travel into another building, the tower was considered a horizontal exit for the Administration building. The main reason that this needed to be considered is because the tower is the main entry point into both sections of the structure, but is physically a part of the Student building, regarding egress. A horizontal exit, as per NFPA 101 7.2.4.1.2, is permitted to be substituted for other exits when the egress capacity and number of other exits is not less than half that is required. A horizontal exit is a way of passage from one building to an area of refuge in another building on the same level. An area of refuge gives safety from fire and smoke from the area of incidence, as per NFPA 101 3.3.83.1. A horizontal exit requires a two hour wall/partition and a one and a half hour fire door assembly fire rating, as per NFPA 101 Table 8.3.4.2.

To achieve the necessary fire ratings that are required on the glass curtain walls, fire resistive glazing was analyzed. Different fire-rated glass wall panels have fire ratings of up to two hours and have up to Category II impact safety ratings. This is important for the exterior walls.

To achieve the ratings that are required by a horizontal exit, the exterior walls and ceiling of the tower, as well as the curtain wall between the tower and the Administration building, must have a two hour rating, while the curtain wall between the tower and the Student building must have a one hour rating. This is because the horizontal exit separates the tower from the Administration building, and is a part of the Student building.

5.1.5 Travel Distance

Travel distance also must analyzed in regards to an egress system. Because assembly type space is the majority of the building, and a person would have to go through assembly type spaces to reach the exit access, assembly travel distances are analyzed. Assembly travel distance is also the most restrictive among the occupancies within the building. As per section 1014.3 of the IBC, the common path of travel for egress cannot exceed seventy-five feet. The maximum travel distance within a sprinklered building is two hundred and fifty feet, as per Table 1016.1 in the IBC. Both of the sections of the Gateway Campus Center meet the sprinklered requirements, meaning the entire building can have a common path of travel of 250ft with the common path of travel being less than 75 ft.

TABLE 1016.1 EXIT ACCESS TRAVEL DISTANCE[a]

OCCUPANCY	WITHOUT SPRINKLER SYSTEM (feet)	WITH SPRINKLER SYSTEM (feet)
A, E, F-1, M, R, S-1	200	250[b]
I-1	Not Permitted	250[c]
B	200	300[c]
F-2, S-2, U	300	400[c]
H-1	Not Permitted	75[c]
H-2	Not Permitted	100[c]
H-3	Not Permitted	150[c]
H-4	Not Permitted	175[c]
H-5	Not Permitted	200[c]
I-2, I-3, I-4	Not Permitted	200[c]

Figure 52: Travel Distance

Due to the Gateway Campus Center design meeting egress requirements of exit capacity, number of exits, travel distance, and common path of travel, the building meets code.

5.2 Fire Protection Suppression Design

The Gateway Campus Center is fully sprinklered in accordance with NFPA 13. This code is prescriptive in how a building should be sprinklered regarding the hazard classification and the occupancy classification of the space. Dependent on the occupancy hazard and commodity classification of the space, different sprinklers will be used. Sprinklers vary by having different K-factors (orifice size), discharge densities (gpm) and pressures (psi). Depending on the occupancy hazard classification, the density per area can be determined by Figure 11.2.3.1.1 in NFPA 13, which is reproduced in Figure 53.

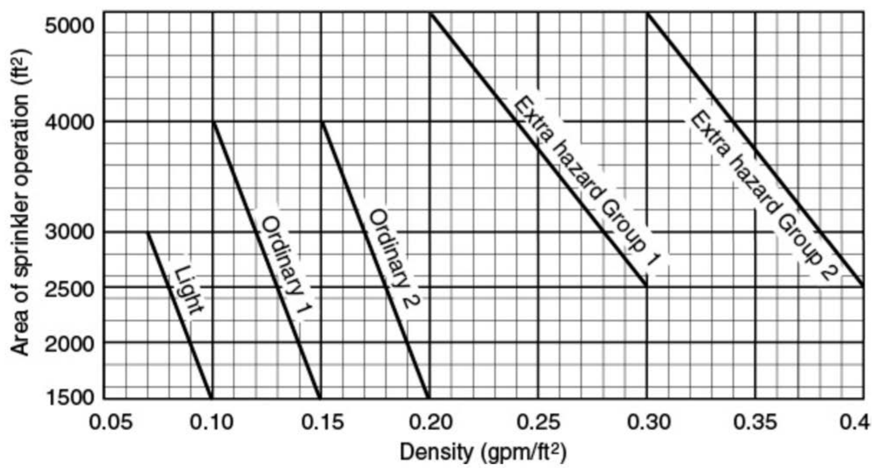

Figure 53: NFPA 13 Figure 11.2.3.1.1 Density/Area Curves

5.2.1 Occupancy Hazard and Commodity Classifications

Each room within the Student and Administration buildings was analyzed individually to determine the occupancy hazard and if there was any commodity classification. In doing this, it was determined that the majority of the building would be light hazard with a sprinkler K-factor of 5.6, a discharge density of 0.1gpm over a design area of 1500 square feet. These results can be found in **Error! Reference source not found.**.

Table 9: Sprinkler Calculations

	Area	Occupancy Hazard	Commodity Classification	Sprinkler K-Factor	Density (gpm)	Design Area (sqft)
Student Building	loading dock	ordinary group 1	class I-IV, group A plastics (foods and packaging)	K-5.6	0.15	1500
	kitchen	ordinary group 1		K-5.6	0.15	1500
	lounge	light		K-5.6	0.1	1500
	eatery	light		K-5.6	0.1	1500
	water pump/mechanical	extra group 1		K-11.2	0.3	2500
	gym/dance studio	light		K-5.6	0.1	1500
	locker rooms	light		K-5.6	0.1	1500
	tech suites	light		K-5.6	0.1	1500
	gaming space	light		K-5.6	0.1	1500
dministration Buildin	convenience store	ordinary group 2		K-5.6	0.2	1500
	coffee bar	light		K-5.6	0.1	1500
	coffee bar storage	ordinary group 1	class II, III (bakery, coffee beans)	K-5.6	0.15	1500
	lounge	light		K-5.6	0.1	1500
	store storage	ordinary group 1	class I, II, III (textiles, foods)	K-5.6	0.15	1500
	janitor's closet	ordinary group 1	class III (cleaners/aerosols)	K-5.6	0.15	1500
	lounge	light		K-5.6	0.1	1500
	office	light		K-5.6	0.1	1500
	conference rooms	light		K-5.6	0.1	1500
	resource room	light		K-5.6	0.1	1500
	water pump/mechanical	extra group 1		K-11.2	0.3	2500
	lounge	light		K-5.6	0.1	1500
	tech suite	light		K-5.6	0.1	1500
	outdoor storage	light		K-5.6	0.1	1500

Ordinary and extra hazards also are seen in the building. The loading docks, kitchen, janitor's closet, and storage spaces are considered to be Ordinary Hazard Group 1 occupancies with the maximum commodity classification being Group A Plastics in the loading dock area for foods and packaging. These areas would also have sprinklers with a K-factor of 5.6, but would have a design density of 0.15gpm over a 1500 square foot design area. The convenience store would be considered an Ordinary Hazard Group 2 occupancy with the same sprinkler as before but having a design density of 0.2gpm over a 1500 square foot design area. The Extra Hazard Group 1 areas include the water pump/mechanical rooms in both sections of the building. These sprinklers have a K-factor of 11.2 and a design density of 0.3gpm over 2500 square feet.

5.2.2 System Type

As is generally practiced, a wet pipe sprinkler system was used for the Gateway Campus Center, since there was no area that would sustain temperatures under forty degrees for an extended period of time. Due to this, there would not be any chance of the sprinkler piping becoming frozen. The only area of concern would be the tower due to the constant opening of the entrance doors, and the structure being primarily of glass. Since this space was conditioned, and chance of HVAC failure is low, the chance of sprinklers freezing was not a concern.

5.2.3 Pipe

The sprinkler layouts for each floor of the building, as well as the tower, can be seen in Appendix K. The sprinkler system was laid out using Schedule 10 Black Steel Pipe in sections under fourteen feet, which is the standard for construction. Schedule 10 Black Steel Pipe was selected because the system considered is roll grooved, and as per NFPA 13 Section 6.3.2, Schedule 10 Pipe is to be used in pipes five inches or smaller.

5.2.4 Sprinklers

Three types of sprinklers were used. All three were Victaulic sprinklers, and the respective cut sheets can be seen in Appendix F. The three Victaulic sprinklers that were chosen include standard spray K-5.6 and K-11.2 sprinklers, and storage K-5.6 sprinklers. The sprinklers had a maximum 120 square foot coverage per sprinkler and were a maximum of seven and a half feet and a minimum of six inches off walls. Due to the unique architectural layout, the sprinkler system does not utilize normal branch lines or square design areas.

Different orientations of sprinklers were used. For the Administration building, concealed pendent sprinklers were used, which were centered in 2’x2’ ACT ceiling tiles. In the Student building and the tower, upright sprinklers were used, due to the exposed construction. Because of this, there was no need to conceal the sprinklers. Additionally, upright sprinklers can wet the structural components in the event of a fire.

5.2.5 Water Supply and Hydraulic Analysis

Once the sprinkler system was laid out, a water supply needed to be determined. Since the Student and Administration buildings did not connect on each floor, two risers were placed in the Campus Center, one at each enclosed exit stair. The tower's system was supplied through the main feed from the Student building third floor. Data on the available water supply was taken from a recent construction project on the lot adjacent to the site. The water flow test yielded a static pressure of 140psi, and a residual pressure of 135psi at a 1695gpm flow. This was obtained by the project manager of a recently built hotel on the adjacent lot, who took measurements on October 3, 2014.

Hydraulic analysis was then performed on the sprinkler system to determine if a fire pump would be needed to supplement the water supply. A two and a half inch main was used on all floors of the building, and branch lines included one inch, one and a quarter inch, and one and a half inch, depending on how many sprinklers were on the line. One inch pipe was used on lines up to three sprinkler heads, one and a quarter inch pipe was used on parts of lines between three and five sprinkler heads, and one and a half inch pipe was used on parts of lines having more than five sprinkler heads. Three calculations were done on the third floor of the student building, and one was done on the second floor of the Administration building. Calculations were only done on the top floors of each building because each floor had similar numbers of sprinklers, so the maximum pressure would be on the top floor, where there would be the maximum amount of pressure loss due to elevation.

Table 10: Fire Protection Cost Analysis

Roll Grooved				
Schedule 10, threaded with couplings and cleavis hanger (labor and material)				
Pipe Type	Main	Line		
Size (in)	2.5	1	1.25	1.5
Basement	145	363	29	
First Floor	255	798	93	5
Second Floor	315	912	116	10
Third Floor	215	579	88	
Total	930	2652	326	15
	$ 27.50	$ 12.65	$ 14.70	$ 16.85
$ 64,167.75	$25,575.00	$33,547.80	$4,792.20	$ 252.75

Threaded				
Schedule 40, threaded with couplings and cleavis hanger (labor and material)				
Pipe Type	Main	Line		
Size (in)	2.5	1	1.25	1.5
Basement	145	363	29	
First Floor	255	798	93	5
Second Floor	315	912	116	10
Third Floor	215	579	88	
Total	930	2652	326	15
	$ 42.00	$ 18.85	$ 21.50	$ 24.00
$ 96,419.20	$39,060.00	$49,990.20	$7,009.00	$ 360.00

The test with the most demand was the tower design area. This area includes K-11.2 sprinkler heads to account for the distance the water needs to travel from the ceiling of the tower to the ground level. This area is 51.1 psi under the available pressure and is also under the available flow, so the demand is less than the supply. This was good because this means that the system does not require a fire pump. The different hydraulic tests can be seen in Appendix G.

The tower sprinkler system would need to be re-evaluated if this building design is taken into consideration for construction. This is due to the fact that the tower was designed after the sprinkler system. The system is sufficient for the enclosure of the tower, but the decision for a structural member protruding into the tower presents different obstruction issues. The new obstruction in the tower may require additional sprinkler protection depending on the size, location, and orientation of the obstruction. The requirements for this can be found in NFPA 13.

5.2.6 Cost Analysis

A cost analysis was completed for the designed system. The system chosen for the Gateway Campus Center was a roll grooved system; a threaded system was also analyzed for comparison. The data for this cost analysis was found in the 2011 edition of *R.S. Means Mechanical Cost Analysis*, and then was pro-rated using the correct Worcester location factor of 125.1 for 2015. Cost estimates were prepared for both pipe and pipe plus sprinklers. Both included the materials, labor, overhead, and profit. The total cost of the roll grooved system was calculated to be about $88,000, $40,000 less than the price of the threaded system.

Table 11: Fire Protection Cost Analysis with Location Factor

2015	Worcester: 125.1 location factor		
Pipe (O and P)	Grooved	$ 80,273.86	$2.86/sqft
	Threaded	$120,620.42	$4.30/sqft
Pipe+Sprinklers (O and P)	Grooved	$ 87,508.36	$3.12/sqft
	Threaded	$127,854.92	$4.55/sqft

Once the total price was known for the system, the price per square foot was calculated. This was done by dividing the total calculated cost for the system by the square footage total, 28080sqft for the entire facility. By doing this, the cost per square foot for the entire system was $3.12/sqft. The calculated $4.55/sqft threaded system number was checked against a typical threaded system cost in San Francisco, CA to determine if the system cost per square feet is accurate. The information for the price per square foot for a typical threaded system in California was described in the San Francisco Department of Building Inspection paper of 2015 Cost Schedule. The location factor was adjusted to account for the change in location, but the Worcester, MA location was found to be $4.83/sqft, which is very close to the calculated $4.55/sqft for this project.

Table 12: Cost Check per Square Foot

2015	san francisco 138.6 location factor	
	28000 sqft	$5.35/sqft
2015	125.1 location factor (worcester)	
	28000 sqft	$4.83/sqft

6.0 HVAC Design

The HVAC design, referring to the heating, ventilation, and air conditioning, is an important factor of building design. The interior building systems or the MEP trade (mechanical, electrical, and plumbing) systems have a large impact on the comfort and operation of the building. These trades also tend to drive the cost of constructing the building and are important to consider throughout the entire design and construction process.

6.1 Load Calculations and Discussion of Implications

To determine mechanical system sizing and capacity requirements for the HVAC system, Peak Cooling Load and Heating Load calculations must be performed. For the mechanical design of this building, the CLF/CLTD method for heating and cooling load calculation was used. To determine the building peak cooling load, factors such as building orientation, building location, glazing area, and the thermal properties of building materials all play an important role. Internal heat gains from people, lights, and equipment also have a significant impact upon the cooling load. For heating loads, the amount of heat loss through the surfaces of the building must be calculated. The heating system of the building is required to supply the heat loss from each room.

When considering the design and implementation of heating, ventilating, and air-conditioning system (HVAC) systems in a space, the primary function of the system is for the generation and maintenance of comfort for occupants in a conditioned space, and/or the supplying of a set of environmental conditions for a process (ASHRAE 2013, Chapter 1, Principles of Heating, Ventilating & Air Conditioning, 7th Ed). For the purposes of this report, an HVAC system was designed to provide year-round control of temperature, humidity, and airflow among other conditions. The design of this particular HVAC system must provide comfort for a wide range of building uses, spanning from a workout/gym area, to a conference room or technical suite.

Typically, a HVAC design engineer considers various system options and variations to choose a system that aligns well with the client's intent for the project. In this case, Worcester Polytechnic Institute is committed to incorporating the values of sustainable design in all aspects of the building process. These design requirements will have a significant effect on the weight of the design criteria. The new Gateway Campus Center, as mentioned earlier, seeks to function as a center for the lower campus of WPI, providing this part of campus with a multi-use student and faculty center. The multi-use nature of the building will also affect the criteria weighting for the design of the HVAC systems.

Along with these important design considerations, there are many other criteria required in selecting an appropriate system. The graphic below, Figure 54, outlines the general process for HVAC system analysis and selection defined by the *2008 ASHRAE Handbook - HVAC Systems and Equipment*.

Figure 54: General HVAC system analysis and selection process defined by ASHRAE Handbook

The first step in selecting an HVAC system for a building is to designate important goal criteria to the project. A design engineer must determine which criteria are important to the project in terms of satisfying both the design specifications, as well as owner preference. The team created a list of goal criteria for the project and identified the system constraints on the project as far as constructability and spatial requirements. The list of goal criteria that were determined to be pertinent to the HVAC design can be seen in Figure 55.

Figure 55: List of goal criteria pertinent to the HVAC design

Moving forward, once the goal criteria are established, they must be weighted to determine the importance of each criterion to the design. As mentioned previously, an initiative of all new WPI buildings is achieving LEED accreditation. Therefore sustainability is an important design criterion. In a typical system selection process, the owner or client would provide the weighting for the goal criteria. Although the sustainability initiative for the WPI provides insight into the importance of sustainability in the design, without sponsor interaction, it is difficult to determine the importance of other goal criteria. Therefore, students in the architectural engineering department at Worcester Polytechnic Institute and other students familiar with the project were surveyed on their opinions of the importance of each goal criteria. Each student ranked each criterion on a scale from 1 to 5. The average score was then determined for each criterion, and this value was applied to the matrix as the weighted value associated with each goal criterion.

For this project, the following HVAC system types were considered for the Gateway Campus Center:

1. Single Duct CAV – Constant air volume system that conditions air at a central source. Supply and Return fans circulate the air through the occupied spaces and a master thermostat controls the central heating and cooling. There is no individual temperature control as the entire building is on one zone.
2. Single Duct VAV with Radiators– Variable air volume system that conditions air at a central source. Supply and Return fans are used to circulate the air through the occupied spaces and thermostats control the temperature at each zone. There is a single run of duct that supplies cooling to the conditioned space. Baseboard radiators are used to heat the conditioned space.
3. VAV with Fan Boxes – Variable air volume system is identical to the single duct VAV system with supplemental radiators except for the fact that it uses the fan box to heat and cool the space. The single run of duct supplies cooling to the conditioned space. The fan-powered boxes act as terminal heating units, using returned plenum air to help heat the required spaces.
4. Dual Duct VAV - Variable air volume system that conditions air at a central source. The system uses a pair of side-by-side ducts that carry both heated and cooled air to each zone. The two airstreams mix locally at the zone to achieve the desired room temperature and conditions. This system provides excellent temperature control but requires two times the amount of ductwork.
5. Geothermal Heat Pump – A system that provides heat from a source to a heat sink. A heat pump moves thermal energy opposed the direction of traditional heat flow,

pulling in heat from a cold space and releasing it to a warmer one. A geothermal heat pump uses underground pipes to capture the heat from the crust of the earth and transfer it to the conditioned space. The heat pump also removes hot air from the space in the summer and leaves cooler conditioned air. A geothermal heat pump system requires one pump per zone.

6. Active Chilled Beam – Ducted primary air is supplied to the space to maintain ventilation and latent load requirements. The ducted air supply is used by the chilled beam to induce secondary air cross the heat transfer coil where it is reconditioned prior to mixing with the primary air that is being discharged into the space. The heat transfer coil accounts for the sensible load of the space and does not provide latent cooling or humidity control.
7. DOAS/Radiant Cooling – Direct outside air system uses primary air directly from outside to meet the latent and humidification requirements of the conditioned space. The outdoor air also has the ability to handle some of the sensible load and improves indoor air quality and thermal comfort. A parallel radiant system is used to accommodate the sensible load of the space.
8. Multiple Rooftops – A multiple rooftop system is similar to that of the geothermal heat pump system in that there is one unit per zone. However instead of the heat being rejected into a water loop, it is rejected directly outdoors to the air. Multiple rooftop units require several vertical ducts of supply air.

After consideration of these systems, each was ranked for each of the goal criteria identified in Figure 55. Intensive research is required to compare similar systems and to determine the value that should be assigned to each system within each criterion. The ranking was based on a scale of 1 to 5, with 5 being superior performance in that category. For example, to determine the life cycle value assigned to each system, the building was modeled with Design Builder, an energy simulation software tool, to determine the building energy simulation. From there, an analysis of the life-cycle cost for each proposed system was performed to determine how each system ranked comparatively. Figure 56 below displays the final values assigned to all of the proposed HVAC systems for each criterion.

		CAV	VAV with Radiators	VAV w/Fan Boxes	Dual Duct VAV	Geothermal Heat Pump	Chilled Beam	DOAS/Radiant Cooling	Multiple Rooftops
Criteria Rating	Initial Cost	4	4	4	3	2	2	2	4
	Operating Cost	3	4	4	4	4	4	4	2
	Maintenance Cost	3	3	3	3	4	5	5	2
	Life Cycle Analysis	4	3	3	3	5	5	3	2
	Reliability	3	3	3	3	3	3	3	3
	Flexibility (Zones & Controls)	3	5	5	5	3	3	3	2
	Humidity Control	3	4	4	4	4	4	4	3
	Capacity Requirements	4	4	4	4	4	3	3	4
	Environmental Impact	2	3	3	3	5	4	4	3
	Sustainability	3	3	3	3	4	4	4	3
	Efficiency	3	3	4	3	5	5	4	3
	Constructability	5	5	5	5	3	2	2	2
	Aesthetics	3	3	3	3	3	5	5	4
	Noise	3	4	5	4	4	5	4	4
	Local Exhaust Requirements	4	5	4	4	1	3	4	3

Figure 56: Final criteria rating used for HVAC system selection

Once the system relative rankings were established, a decision matrix can be used to determine the best system for the criteria and constraints of the project. Using the weighted criteria and the assigned relative ranking values for each criterion by system, an ideal system can be chosen. The matrix takes the weighted value assigned to each criterion and multiplies it by the value assigned to each system for that particular criterion. For instance, if there was a system that was assigned a five (5) for Initial cost, meaning it was the most competitive of all the systems for initial cost, and the weighted value for initial cost was considered to be "Very Important" (5), the value for that system with the weighted criterion would be twenty-five (25). A total for each system would be determined by adding the weighted values for all 16 criterions. The system with the highest total would be the "best" system for the constraints and criteria specified by the project. Figure 57 shows the decision matrix used on the Gateway Campus Center to determine that Chilled Beam is the preferred system for the building. Figure 57 below displays the results of the system selection matrix.

Goal Criteria	Criteria Weighting	Weight	CAV	VAV with Radiators	VAV w/Fan Boxes	Dual Duct VAV	Geothermal Heat Pump	Chilled Beam	DOAS/Radiant Cooling	Multiple Rooftops
Initial Cost	Important	4	16	16	16	12	8	8	8	16
Operating Cost	Very Important	5	15	20	20	20	20	20	20	10
Maintenance Cost	Important	4	12	12	12	12	16	20	20	8
Life Cycle Analysis	Very Important	5	20	15	15	15	25	25	15	10
Reliability	Very Important	5	15	15	15	15	15	15	15	15
Flexibility (Zones & Controls)	Important	4	12	20	20	20	12	12	12	8
Humidity Control	Moderately Imp	3	9	12	12	12	12	12	12	9
Capacity Requirements	Moderately Imp	3	12	12	12	12	12	9	9	12
Environmental Impact	Important	4	8	12	12	12	20	16	16	12
Sustainability	Very Important	5	15	15	15	15	20	20	20	15
Efficiency	Very Important	5	15	15	20	15	25	25	20	15
Constructability	Important	4	20	20	20	20	12	8	8	8
Aesthetics	Less Important	2	6	6	6	6	6	10	10	8
Noise	Moderately Imp	3	9	12	15	12	12	15	12	12
Local Exhaust Requirements	Moderately Imp	3	12	15	12	12	3	9	12	9
HVAC System Selection Matrix		Total	196	217	222	210	218	224	209	167
		Rank	7	4	2	5	3	1	6	8

Figure 57: HVAC System Selection Matrix

However, although Chilled Beam scored the highest with the decision matrix, a sensitivity analysis was performed to see exactly what other alternative assumptions might cause another system to rank first. A sensitivity analysis is basically the practice of recalculating outcomes using different or alternative assumptions that differ from the initial assumptions. The goal is to determine if the alternative assumptions have any impact on the variable.

To perform the sensitivity analysis on the initial decision matrix, scenarios for each criterion were created. Since each criterion's weight was determined by an average of survey results, there were several criterion somewhere in between two integers. To determine the effect that each criterion would have on the overall system selection, a scenario was created for each criterion with a decimal value, and both the integer below and above the number were used to determine the effect of each criterion. For example, if the average for the weight of the initial cost criterion was determined to be a value of 4.5, scenarios would be created for an instance in which initial cost was weighted as a five (5) and for when it was weighted as a four (4). A scenario summary in Figure 58 includes the sensitivity analysis for a change in weighted value for all criteria. The scenario summary, displays the sensitivity analysis for all the criterion with standard rounding, actual value, and slight variations in each individual criterions' ranking.

Scenario Summary	Selected Values (Sustainable):	Actual Value	Standard Rounding	Initial Cost @3	Operating Cost @4	Maintenance Cost @3	Life Cycle Analysis @4	Reliability @4	Flexibility @3	Humidity Control @3	Capacity Requirements @3	Environmental Impact @3	Sustainability @4	Efficiency @4	Constructability @3	Aesthetics @1	Noise @3	Local Exhaust Requirments @2
Changing Cells:																		
Initial Cost	4	3.8	4	3	4	4	4	4	4	4	4	4	4	4	4	4	4	4
Operating Cost	5	4.8	5	5	4	5	5	5	5	5	5	5	5	5	5	5	5	5
Maintenance Cost	4	3.9	4	4	4	3	4	4	4	4	4	4	4	4	4	4	4	4
Life Cycle Analysis	5	4.3	4	5	5	5	4	5	5	5	5	5	5	5	5	5	5	5
Reliability	5	4.5	5	5	5	5	5	4	5	5	5	5	5	5	5	5	5	5
Flexibility (Zones & Controls)	4	3.6	4	4	4	4	4	4	3	4	4	4	4	4	4	4	4	4
Humidity Control	3	3.4	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
Capacity Requirements	3	3.3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
Environmental Impact	4	3.8	4	4	4	4	4	4	4	4	4	3	4	4	4	4	4	4
Sustainability	5	4.2	4	5	5	5	5	5	5	5	5	5	4	5	5	5	5	5
Efficiency	5	4.2	4	5	5	5	5	5	5	5	5	5	5	4	5	5	5	5
Constructability	4	3.5	4	4	4	4	4	4	4	4	4	4	4	4	3	4	4	4
Aesthetics	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	1	2	2
Noise	3	3.2	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
Local Exhaust Requirements	3	2.9	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	2
Result Cells:																		
CAV	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7
VAV w/Radiators	4	3	3	4	4	3	3	4	4	4	4	3	3	3	4	4	4	4
VAV w/Fan Boxes	2	2	1	2	2	1	1	2	2	2	2	2	2	2	2	1	2	2
Dual Duct VAV	5	5	5	5	5	5	5	5	6	5	5	5	5	5	6	5	5	5
Geothermal Heat Pump	3	4	4	3	3	3	4	3	3	3	3	4	3	4	3	3	3	3
Chilled Beam	1	1	2	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
DOAS/Radiant Cooling	6	6	6	5	6	6	6	6	5	6	6	6	6	6	5	6	6	6
Multiple Rooftops	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8

Notes: Current Values column represents values of changing cells at time Scenario Summary Report was created. Changing cells for each scenario are highlighted in gray.

1st Place | 2nd Place | 3rd Place | 4th & Worse

Figure 58: Sensitivity Analysis – HVAC System Selection

Upon evaluation of sensitivity analyses results, there is conclusive data demonstrating that the initial findings of the decision matrix were inaccurate to a degree. In several of the alterations in the sensitivity analysis, VAV with Fan Boxes tied Chilled Beam as the best system for the Gateway Campus Center and on one occasion, it surpassed Chilled Beam. Upon further research and evaluation of each of these two systems it was decided that the building will use a combination of the two. The Administration building will use active chilled beams while the Student building and the tower will use a VAV system. After consultation with several sources, it was determined that chilled beam was not a preferred application for buildings with large assembly areas, cafeterias or gymnasiums. Since a majority of the architectural program of the Student building fell under these categories, it was determined that VAV would be a more viable solution due to its ability to exhaust large quantities of air and to offset the large sensible loads present in that section of the building.

6.2 HVAC Systems Explained

6.2.1 VAV – Variable Air Volume

To better understand why VAV was chosen for the Student building, a further explanation of how VAV systems work is required. VAV or a variable air volume is an all air system that uses a central source to condition air. For the Student building, a single-packaged central heating and cooling system was used. This system combines the capabilities of a boiler room and chimney with a chiller and a fan room. In the case of the Student building, the supply and return air are connected through the roof and ducted to the necessary zones. Figure 59 below is an example of a single-packaged unit.

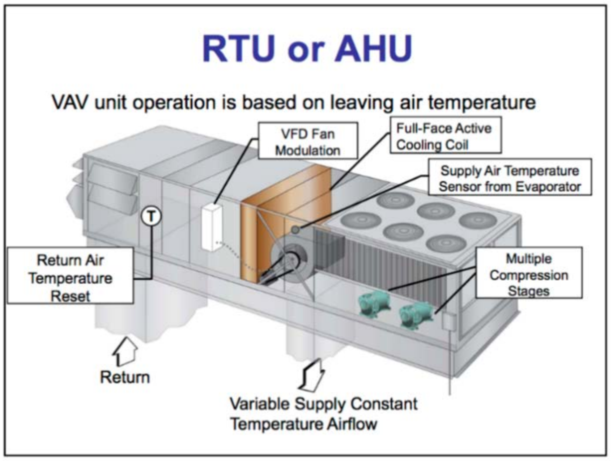

Figure 59: Single-packaged Air Handling Unit

The two primary variations of VAV are single-duct and dual-duct systems. A single-duct system uses a single supply fan and single run of supply duct to condition each space. The supply duct provides each VAV box and its corresponding zone with primary air to condition the space. The units considered for the Student building were central cooling only; no heat, and require the use of terminal units to supplement the heating load. Due to the fact that several spaces within the Student building had varying solar loads, it was determined that a heating-changeover system would not be effective. Instead, it was determined that terminal heating in a few spaces would be a more cost efficient option. Instead of the entire system providing heating or cooling, the terminal units would deliver the required medium to the desired spaces. The variations of VAV with terminal heating will be discussed in Sections 6.2.1.1 VAV with Fan Boxes and 6.2.1.2. VAV is a versatile system that has the ability to supply large amounts of conditioned air to a space while supplying a small amount of air to another zone at the same time. This versatility is necessary in the Student building with several large assembly spaces throughout the building. Also, as specified earlier, the Student building has a large solar load that fluctuates throughout the day, VAV provides the system with the ideal flexibility to handle these varying loads.

6.2.1.1 VAV with Fan Boxes

VAV terminal fan boxes are used as a terminal heating method to provide heating to some zones of a single-duct system. The two variations of fan-powered heat are parallel and series. A parallel fan-powered terminal unit operates by mixing warm plenum air with cool supply air that is provided at a minimum level. The fan from the terminal unit which is in parallel with the primary fan draws air from the plenum whenever the space requires heating. Parallel fan-powered terminal units are often used for perimeter zones and paired with single-duct units in interior spaces to operate efficiently.

A series fan-powered terminal uses a constant air delivery to the space to provide heating and cooling. The fan operates whenever the unit is in occupied mode and the temperature of the air delivered varies. When the zone requires less cooling, the primary air damper closes and the mixed air that is supplied to the zone contains less cooled air and more warm air from the plenum. The terminal unit fan is in series with the central fan, and the air always passes from the central fan through the terminal unit fan. Series fan-powered terminal units are usually used in applications where a constant supply of ventilation air is required; spaces where this application is often used include lobbies, conference rooms, and more recently, office buildings. Figure 60 displays typical series and parallel fan-powered terminal units.

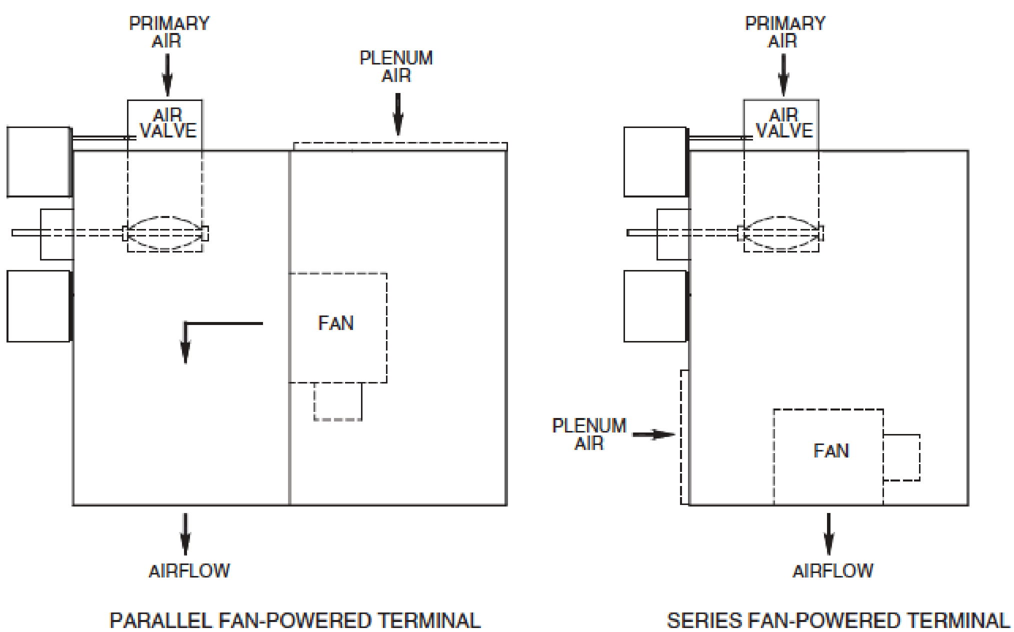

Figure 60: Fan-Powered Terminal Units

6.2.1.2 VAV with Reheat

A single duct VAV can use a classic VAV terminal unit to supply heating to the zone when necessary. To do this, the single-duct terminal unit uses a reheat electrical or hot water coil. VAV with reheat is identical to single-duct VAV until the air enters the local ductwork. From there, the air passes over a heating coil before it is distributed to the zone diffusers. Local temperature control determines the flow of water or electricity to the reheat coil. This application is efficient and effective in providing close individual control of the zone temperature. Figure 61 below provides a diagram of a typical single-duct VAV terminal reheat system.

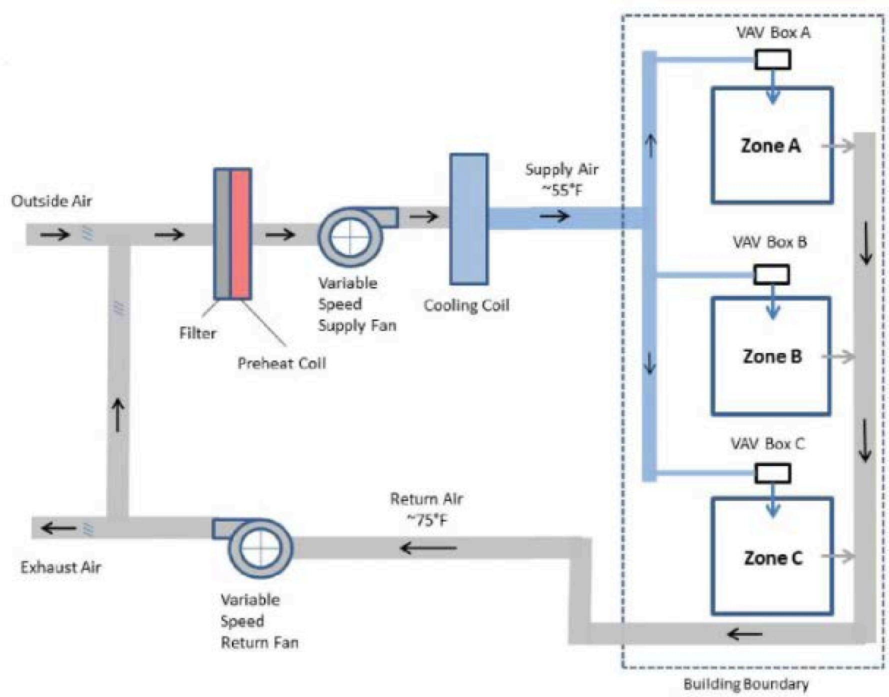

Figure 61: Single-Duct VAV Terminal Reheat System

6.2.1.3 VAV Conclusions

Upon further evaluation of the variations of VAV system types and the use of the system selection matrix, a combination of series fan-powered and single-duct reheat units were used to meet the diverse heating and cooling loads of the Student building. The series fan-powered terminal units were installed in the zones where a constant air flow was required; therefore they were placed in areas such as the cafeteria, lounge area and the gym.

The single-duct reheat terminal units were placed in internal spaces where there is a minimum requirement for heating. These terminals effectively heat the interior spaces with reheat while maintaining the ventilation minimum requirements. Section 6.3.1 outlines the building loads with Table 16 displaying the peak cooling load breakdown for each building. Appendix A provides the entire mechanical load summary.

6.2.2 Active Chilled Beam

Using the system selection matrix, and further research of active chilled beam systems, it was determined that the Administration building would be suitable for application of active chilled beams. Active chilled beams take advantage of the higher cooling efficiency of water over air to provide sensible cooling to a space. The chilled water heat exchanger cooling coils located on each beam help to cool the induced air. Figure 62 below shows the typical operation of an active chilled beam.

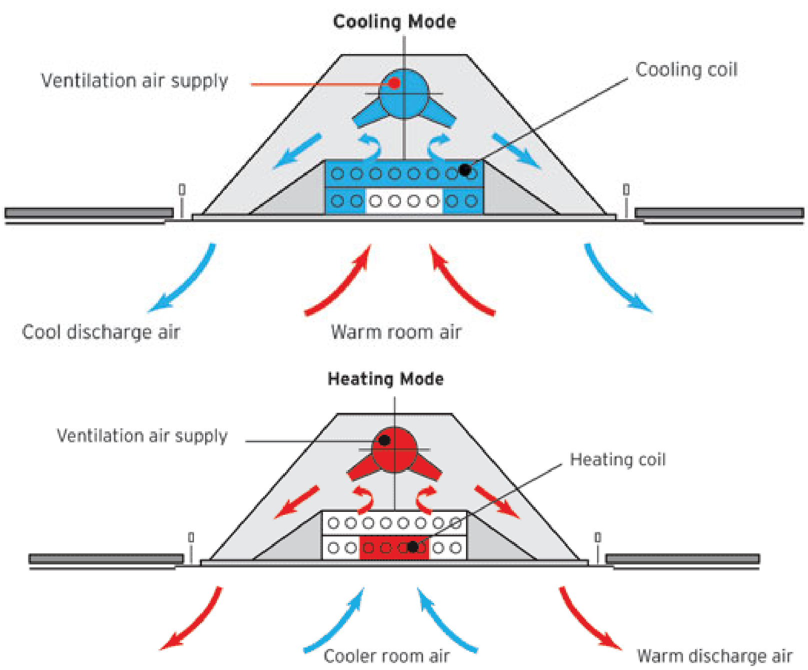

Figure 62: Typical Operation of Active Chilled Beams

In an active chilled beam, ducted primary air from the central air handling unit is supplied to each beam. The beam uses a combination of the supply air and recycled room air to supply the required cooling or heating for the space. In order to recondition the air from the space, the beam injects air into the space through a nozzle via the supply air while also inducing air across the cooling coils. The reconditioned air mixes with the primary air and is discharged into the space via a slot diffuser. The primary air supplied to the system must meet the ventilation or latent heat requirement while the sensible cooling load is met through the secondary cooling ability of the beam.

6.3 HVAC System Design

6.3.1 Student Building Design: VAV

With the selection of a Single Duct VAV system with fan boxes for the Student building, the cooling load and heating load of the building must be determined in order to properly size the systems and ductwork. The design conditions for this building were determined from the information provided in Tables 1.1 and A.9 of *Air Conditioning principles and Systems* by Edward G. Pita. Both of these charts were adapted from the *ASHRAE Handbook*. The tables are summarized below in Table 13 and Table 14, modified for this project's purposes.

Table 13: Outdoor Design Conditions

Outdoor Design Conditions				
Worcester, MA				
Heating		Cooling		
LAT	DB	DB	WB	DR
42	0	85	74	17
LAT = Latitude				
DB = Dry Bulb Temperature				
WB = Wet Bulb Temperature				
DR = Daily Range				
Abridged from 1997 ASHRAE Handbook - Fundamentals				

Table 14: Indoor Air Design Conditions

Recommended Energy Conserving Indoor Air Design Conditions			
	Air Temperature (DB) F	Relative Humidity* (RH) %	Max Air Velocity FPM
Winter	68-72	25-30	30
Summer	76-78	50-55	50
*ASHRAE Standard 62.1-2013 Requires RH to be under 65%			

Heat transfer coefficient u-values must also be determined for all external surfaces for which there will be external heat gains for each room. The external wall for the building was designed to be a 16" thick wall with steel stud and brick. The wall section in Figure 63 provides a more detailed representation.

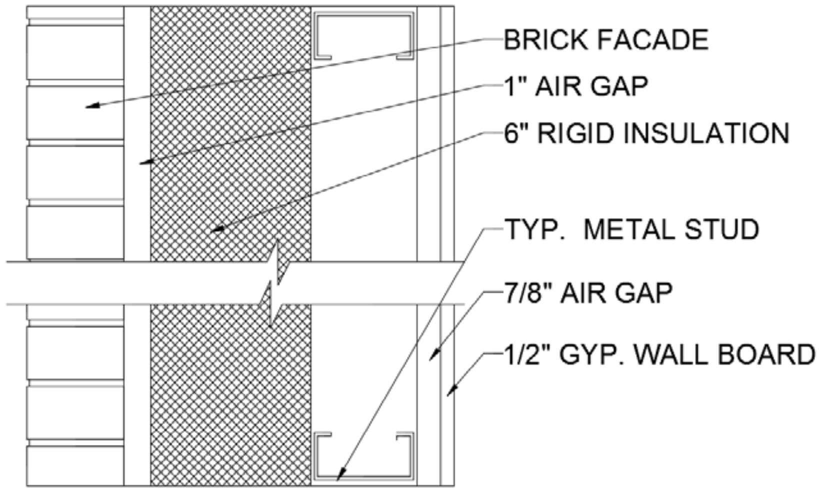

Figure 63: Detailed Wall Section

The windows and glazing in the building are double paned, low-emissivity glass. Double-paned glass has an increased cost but has significantly improved thermal properties to that of single thick glass. Table 15 provides the thermal properties of the building used to perform heating and cooling loads.

Table 15: Building Component Thermal Properties

Building Thermal Properties			
Wall U-value[1]	Glass U-value[2]	Glass SC	Roof U-value
0.05	0.35	0.81	0.05
1. 16" Wall - 8" Metal Stud			
2. Double Glass 3/8" Low-E			

The heat gain from each skin load and internal load were applied to each building space in order to determine the sensible and latent cooling load of the building at the peak load time. Table 16 displays a breakdown of the peak cooling load by internal load and skin load for the Student building. A more comprehensive spreadsheet evaluated individual breakdown of each space can be found in Appendix A.

Table 16: Peak Cooling Load Breakdown

Administration Building							
Skin Load	BTUH	% of Skin	% of Total	Internal Load	BTUH	% of Internal	% of Total
Roof	11611	20%	9%	Light	36140	49%	27%
Wall	9624	17%	7%	People	25750	35%	20%
Glass	36969	64%	28%	Equipment	11650	16%	9%
Total	58203	N/A	44%	Total	73540	N/A	56%
Total RSCL	**131743**	**131.7**	**MBH**	**Total RLCL**	**20600**	**20.6**	**MBH**
Student Building							
Skin Load	BTUHS	% of Skin	% of Total	Internal Load	BTUHS	% of Internal	% of Total
Roof	17028	11%	6%	Light	46980	29%	15%
Wall	10760	7%	3%	People	40250	25%	13%
Glass	121511	81%	39%	Equipment	72031	45%	23%
Total	149299	N/A	48%	Total	159261	N/A	52%
Total RSCL	**308559**	**308.6**	**MBH**	**Total RLCL**	**29200**	**29.2**	**MBH**

Once peak cooling and heating loads are determined, duct layout and design was generated. The duct layout for the Student building was designed using the equal friction method. The ductwork was sized to account for an equal friction of .08 in. w. /100 ft. using table 8.11 from “Air Conditioning Principles and Systems” a recommended air velocity of 1200 fpm (feet per minute) was chosen. The mechanical drawings in Appendix K: Drawings provide the double-line ductwork drawings for the Student building. A Trane Ductulator® was used to calculate the duct sizing. The sizing found using the Ductulator were checked with Autodesk Revit 2016, using the duct sizing feature to design to the specifications determined above. Hand checks of the duct sizing were compared the auto calculation to check that the sizing that Revit provided was accurate.

Once peak cooling and heating loads were determined, a system selection spreadsheet developed by Ken Elovitz was used to select a rooftop unit for the Student Building. The unit selected is a High Efficiency 60 Hz, 40 Ton unit provided by Trane. Appendix H provides the selection spreadsheet used to select the rooftop unit for the Student building.

One important feature of the design for the Student building was due to the architectural design decision to have exposed ductwork. With exposed ductwork, there were several mechanical design decisions used to help cut cost. Due to the fact that no diffusers are needed to provide air from the plenum through a drop down ceiling, side wall diffusers were mounted directly on the side of the duct runs for supply air. A similar strategy was used for the return ductwork. At the end of the duct runs for return duct, an elbow fitting was used and the upturned end of the duct acted as the return “grille”. The exception to the exposed ductwork design is that of the exhaust system designed for the bathroom and locker rooms. In order to heat the restrooms and locker rooms in the Student building, radiant ceiling panels were selected. Due to the need for ceiling tiles, a drop-down ceiling was installed in these spaces.

6.3.2 Student Building Design: Exhaust System

The VAV system designed for the Student building supplies conditioned air to the permanently occupied spaces of the building. To account for the required air exhaust from spaces such as the bathrooms and locker rooms, a mushroom fan exhaust system was selected. The vertical run of duct was tucked inside the plumbing wall, removing the need for a separate shaft for this function. Appendix K: Drawings, drawings M-102, M-104, and M-106 provide the exhaust system in plan view.

For design of the kitchen exhaust, due to the decision made in the architectural process to not design a fully functional kitchen, the exhaust requirements were significantly diminished. The architectural team decided to limit the functionality of the kitchen to reheating and storing previously cooked food that would be trucked from the existing kitchens of either the Rubin Campus Center or the Pulse On Dining Hall in Morgan Hall. Since there will not be any need for specific kitchen exhaust, the system from the kitchen must only be a general exhaust. Therefore, the exhaust for the kitchen was designed with a vertical run of duct running directly from the first floor of the student building to the roof of the student building. From there, this run of the duct runs horizontally across to the vertical run of duct that connects the bathroom and locker room exhaust system to the mushroom fan. Since there was no need for an additional kitchen system, the general exhaust drawn from the kitchen was ducted to the same exhaust fan that was described before.

The kitchen exhaust system was designed for potential expansion. The vertical run of duct runs directly to the roof in case the owners were to decide to use a full kitchen and would need a dedicated kitchen exhaust system. In this scenario, the existing ductwork may be used but an additional exhaust fan could be added to handle the load. If there is no expansion needed, the kitchen exhaust will remain a part of the bathroom exhaust system.

6.3.3 Administration Building Design

The initial steps of the design process for the Active Chilled Beam system are similar to that of the steps taken in the Student building. The peak heating and cooling loads must also be calculated on a space by space basis. However, after these calculations are performed, the amount of primary air that is required to offset the latent load or ventilation requirement specified by *ASHRAE Standard 62.1* must be determined. Figure 64 provides the ventilation requirement per occupancy type.

TABLE 5-1 Typical Ventilation Rate for Difference Spaces According to ASHRAE/EN Standards

2007 and 2010 ASHRAE Standard 62.1 Occupancy Category	Default Occupant Density, ft^2/Occupant		ASHRAE 62.1 Ventilation				Default Ventilation, cfm/person	Default Ventilation, cfm/ft^2	2010 ASHRAE LEED v2 EQc2—Increase Ventilation Requirements	
	ASHRAE Standard 62.1, Number/1000 ft^2	ASHRAE Standard 62.1	R_p, cfm/person	R_a, cfm/ft^2	Default, cfm/person	Default, cfm/ft^2	ASHRAE Standard 62.1	ASHRAE Standard 62.1	Rate, cfm/ft^2	Governing Standard
Daycare (through age 4)	25	40	10	0.18	17	0.43	17	0.43	**0.56**	ASHRAE Standard 62.1
Classrooms (age 9+)	35	29	10	0.12	13	0.46	13	0.45	**0.59**	ASHRAE Standard 62.1
Lecture classroom	65	15	7.5	0.06	8	0.52	8	0.52	**0.68**	ASHRAE Standard 62.1
Lecture hall (fixed seats)	150	7	7.5	0.06	8	1.20	8	1.2	**1.56**	ASHRAE Standard 62.1
Multiuse assembly	100	10	7.5	0.06	8	0.80	8	0.8	**1.04**	ASHRAE Standard 62.1
Restaurant dining rooms	70	14	7.5	0.18	10	0.70	10	0.7	**0.91**	ASHRAE Standard 62.1
Cafeteria/ fast-food dining	100	10	7.5	0.18	9	0.90	9	0.9	**1.17**	ASHRAE Standard 62.1
Conference/meeting	50	20	5	0.06	6	0.30	6	0.3	**0.39**	ASHRAE Standard 62.1
Office space	5	200	5	0.06	17	0.09	17	0.09	**0.12**	ASHRAE Standard 62.1
Retail	15	67	7.5	0.12	16	0.24	16	0.24	**0.31**	ASHRAE Standard 62.1
Mall common areas	40	25	7.5	0.60	9	0.36	9	0.36	**0.47**	ASHRAE Standard 62.1

Figure 64: ASHRAE Ventilation Requirements

With the use of Figure 64 and the *ASHRAE* standards, the primary requirement was determined for each of the spaces. Since chilled beam primary air accounts to offset the latent load and the ventilation requirement for the building, the larger of the two was selected, and this determined the amount of primary air supplied to each space. The Table 17 below shows the resulting ventilation requirements based upon the *ASHRAE* standards.

Table 17: Admin Building Ventilation Requirement

Admin Building				Ashrae 62.1		RLCL		
Room #	Use	Max Occupancy (Pe	CFM/Person	Ventilation (cfm/ft^2	Ventilation (CFM)	BTUHl	CFM	Ventilation/Latent OA Requirement
		Pz	Rp	Ra				CFM PRIMARY AIR
10	Tech Suite	2	5	0.06	18	400	13	18
11	Tech Suite	2	5	0.06	17	400	13	17
12	Tech Suite	2	5	0.06	20	400	13	20
13	Tech Suite	2	5	0.06	19	400	13	19
14	Restroom	3	70	0	210	600	20	210
15	Restroom	3	70	0	210	600	20	210
16	Storage	0	0	1	95	0	0	95
17	Mechanical	0	0	0	0	0	0	0
18	Mechanical	0	0	0	0	0	0	0
19	Mechanical	0	0	0	0	0	0	0
A01	Lounge	20	5	0.06	176	4000	135	176
A02	Lounge	5	5	0.06	49	1000	34	49
A03	Corridor	0	0	0.06	18	0	0	18
101	Retail	5	7.5	0	38	1000	34	38
102	Storage	0	0	1	88	0	0	88
102A	Loading Dock	4	10	0.12	58	800	27	58
103	Restroom	3	70	0	210	600	20	210
104	Restroom	3	70	0	210	600	20	210
105	Kitchen	2	0	0.7	133	400	13	133
106	Mechanical	0	0	0	0	0	0	0
A100	Lounge	20	5	0.06	196	4000	135	196
A101	Lounge	10	5	0.06	73	2000	67	73
201	Office	1	5	0.06	13	200	7	13
202	Office	1	5	0.06	12	200	7	12
203	Office	1	5	0.06	16	200	7	16
204	Mechanical	0	0	0	0	0	0	0
204A	Copy Room	0	5	0.06	5	0	0	5
205	Restroom	3	70	0	210	600	20	210
206	Restroom	3	70	0	210	600	20	210
207	Storage	0	0	1	37	0	0	37
208	Conference	5	5	0.06	37	1000	34	37
209	Storage	0	0	1	130	0	0	130
210	Conference	5	5	0.06	39	1000	34	39
A201	Lounge	20	5	0.06	171	4000	135	171
A202	Corridor	0	0	0.06	9	0	0	9
					Total	25000	843	1031

The sensible cooling and heating loads for each space were then analyzed to properly size the chilled beam system. Consulting chilled beam specifications, the manufacturer supplies an approximate CFM/LF of beam that the primary flow can supply. Using the peak sensible cooling load required based upon the cooling load calculations, the linear feet of chilled beam for each space can be determined. To corroborate this calculation and account for the spacing of these beams, Trox, a manufacturer of chilled beams, provides a chilled beam selection program through an excel document.

The selection program requires the engineer to designate the design conditions and entering air/water conditions. The program also requires the engineer to provide the sensible and latent cooling loads, as well as the heating load. Finally, the program requires an input for the CFM required to each space and the type of beam that the engineer desires. Room conditions are also included to provide information on the occupied space, such as area and the volume of the space, the occupied zone height; as well as the distance between each beam and the distance from the beams to the outside walls of the space. The same calculation was done for the heating application of the chilled beam. However, before the selection program can be used, the engineer must determine the active chilled beam type to be used on the project. Due to sensible air requirements, noise limitations and heating capacity, the Trox DID632A active chilled beam was chosen. The performance data and specifications for this beam type are provided in Appendix J.

The last distinction to be made in beam selection is the decision for between a 2-pipe or 4-pipe setup. The 2-pipe allows for both cooling and heating in the system; however, it only allows for the entire system to either be cooling or heating and cannot heat one space while cooling another. The 4-pipe system has the ability to both heat and cool different spaces concurrently; however, it requires twice as much piping compared to the 2-pipe system. Initially the building was designed with a 2-pipe system but it was determined that a 4-pipe system would better suit the buildings requirements. A 4-pipe system would eliminate the possibility of "thermal shock" to the chiller or boiler.

Basically, when changeover occurs in a 2-pipe system, there is the risk that "chilled" water (relatively cold) water would be supplied to the boiler and cause issues. Also, due to the basement floor, the Administration building requires winter cooling because of a minimal heat gain in the spaces. With a 2-pipe system, the system would not be able to provide winter cooling to the basement while providing heating to other spaces that need it.

One benefit to the 2-pipe system that was not addressed is the fact that a 2-pipe system is often much less expensive than a 4-pipe system. In this case, however, the small building footprint does not require a great deal of pipe. Because of this, it was determined that the improved thermal comfort of the space outweighed the cost of installing the extra piping or the fact that a supplemental heating system would be needed in the basement if a 2-pipe system was chosen. Improved thermal comfort will be achieved since there is no changeover period; both heating and cooling will be able to be supplied simultaneously to the spaces.

One noticeable issue with the active chilled beam system is that the capacity to cool the space is much better than the capacity to heat a space. Due to the superior performance of cooling vs. heating for the active chilled beam system, many of the chilled beams in the spaces had to be oversized in order to meet the heating requirement. Essentially, the cooling requirement for these spaces were met, however more chilled beams were needed to meet the heating requirement. In a few instances, a supplementary heating source was required to meet the heating demand. Instead of designing to these specifications, the temperature of the hot water entering the beams was increased from 120 degrees Fahrenheit to 160 degrees Fahrenheit. Most standard condensing boilers can handle temperatures anywhere from 120-180 degrees Fahrenheit. This increase in the water temperature allowed for each space to use less beam length to achieve the same amount of heating as before. Table 18 provides a breakdown of the heating and cooling loads for each space with the selected chilled beams. The table displays the quantity of chilled beam and the length required to meet each load. Appendix K: Drawings, drawing M-101, M-103, and M-105 provide the placement of the active chilled beams in plan on each floor.

Table 18: Active Chilled Beam Schedule

		ACTIVE CHILLED BEAM SCHEDULE																
		SIZE			PRIMARY AIR					SENSIBLE COOLING				HEATING			
				AIR		ZONE	ZONE LATENT COOLING		MAX.	AIR	WATER	TOTAL	ZONE	AIR	WATER	TOTAL	ZONE
		LENGTH	WIDTH	INLET Ø	FLOW	FLOW	COOLING	HEATING	APD	SIDE	SIDE	SENSIBLE	SENSIBLE	SIDE	SIDE	SENSIBLE	SENSIBLE
Room/Tag	QTY	(FT)	(IN)	(IN)	(CFM)	(CFM)	(BTUH)	(BTUH)	(IN WG)	(BTUH)	(BTUH)	(BTUH)	(BTUH)	(BTUH)	(BTUH)	(BTUH)	(BTUH)
Tech Suite 010	1	6	24	5	110	110	3166	-3805	0.60	1047	-3622	-2576	-2576	-8884	14476	5592	5592
Tech Suite 011	2	4	24	5	60	120	3454	-4151	0.40	571	-2168	-1597	-3194	-4846	9026	4180	8360
Tech Suite 012	2	4	24	5	60	120	3454	-4151	0.40	571	-2168	-1597	-3194	-4846	9026	4180	8360
Tech Suite 013	2	4	24	5	50	100	2878	-3459	0.28	476	-1889	-1413	-2827	-4038	7857	3819	7638
Lounge A01	7	6	24	5	97	679	19543	-23489	0.47	923	-3216	-2293	-16050	-7834	13446	5612	39283
Lounge A02	3	6	24	5	77	231	6649	-7991	0.30	733	-2748	-2015	-6046	-6219	11468	5249	15748
Retail 101	5	6	24	5	96	480	13815	-16605	0.46	913	-3196	-2282	-11410	-7753	13360	5606	28031
Lounge A100	11	6	24	8	113	1243	35776	-43000	0.30	1075	-3484	-2409	-26499	-9126	12909	3782	41604
Lounge A101	7	6	24	5	111	777	22363	-26879	0.62	1056	-3641	-2585	-18094	-8965	14549	5584	39088
Office 201	1	6	24	5	95	95	2734	-3286	0.45	904	-3175	-2271	-2271	-7673	13272	5600	5600
Office 202	1	6	24	5	85	85	2446	-2940	0.36	809	-2952	-2143	-2143	-6865	12329	5464	5464
Office 203	5	4	24	6	73	365	10505	-12627	0.29	695	-2312	-1617	-8085	-5896	8922	3026	15130
Copy Room 203A	1	4	24	6	75	75	2159	-2595	0.31	714	-2178	-1465	-1465	-6057	9070	3012	3012
Conference 208	3	6	24	5	93	279	8030	-9652	0.43	885	-3133	-2248	-6743	-7511	13094	5583	16748
Conference 210	3	6	24	5	87	261	7512	-9029	0.38	828	-2999	-2171	-6514	-7026	12528	5502	16506
Lounge A201	16	6	24	5	111	1776	51116	-61438	0.62	1056	-3641	-2585	-41357	-8965	14549	5584	89345

Once the new quantities of active chilled beams were determined, these calculations were checked against performance data for beam type and length. To determine that the sizing for each space was accurate, the Trox beam selection tool was checked with hand calculations. After checking the performance data, it was determined that the selection tool was accurate in determining length and number of active chilled beams required for each space. The performance data used for the beams is included in Appendix J.

Contrary to the Student building, in the Administration building, drop-down ceilings were used to house the chilled beam system. This was due to a design decision that many of the spaces in the Administration building were smaller and would feel strangely proportioned with exposed ductwork and a lack of ceiling.

One major design consideration for the Administration building was the selection of a DOAS (direct outside air system) system for the active chilled beam system. It is important to note that the exhaust requirements for the Administration building was approximately 1700 CFM with an outside air requirement of about 1030 CFM; essentially there is a large amount of building exhaust vs. the outside air load. Because of this phenomena, it is imperative to use a DOAS system with a heat recovery unit built into it. The DOAS supplies the chilled beam with the primary air for the ventilation or a part of the sensible load; the secondary capacity of the beams supply the rest of the conditioned air required to meet the sensible load.

6.3.4 Administration Building Design: Exhaust System

The design of the exhaust system for the Administration was very similar to that of the system in the Student building, the small rooftop unit was selected to handle the loads of the restrooms. There are also several storage spaces that currently have not been considered. These spaces should be considered further to determine their exhaust requirements.

6.3.5 Radiant Heating Ceiling Tiles

To heat the restroom and locker room areas in both buildings, radiant heating ceiling tiles were chosen. As specified earlier, a drop-down ceiling was added to the bathroom and locker rooms to allow for the use of radiant heating ceiling tiles. This solution is a cost effective solution to providing heating on a room by room basis.

7.0 Implications and Analysis

This project meets a growing need to further unify the community at Worcester Polytechnic Institute. With the expansion at Gateway Park including a new residence hall, there is more student activity within the area. To meet communally, students currently need to go to the main campus. To increase the sense of community within Gateway Park, a new campus center is being proposed to provide students and faculty with an additional center for resources, recreation, and academic space.

7.1 Goals of the MQP

This Major Qualifying Project meets the goals set forth in the beginning phases of the design. The goals met include:

1. Understand how a building is designed and coordinated
2. Develop an architectural design with energy analysis
3. Develop a structural design and analysis
4. Develop a mechanical building design and analysis
5. Develop a fire protection suppression system design
6. Develop a cost analysis

The project meets these goals by including documents for architectural, structural, mechanical, and fire protection designs. This could not have been done without understanding how a building must be designed and coordinated. Once the building was designed, a cost analysis was included.

7.2 LEED Certification

The client for this particular project is Worcester Polytechnic Institute. In February of 2007, WPI's Board of Trustees passed a resolution that requires all new buildings on campus to be designed to meet the requirements of LEED certification. LEED, or Leadership in Energy and Environmental Design is a national rating system developed by the US Green Building Council (USGBC) and promotes a whole-building approach to sustainability (USGBC website). LEED is a practical rating tool that awards credits to buildings on the basis of the following categories: sustainable site development, water savings, energy efficiency, materials and resource selection, and indoor environmental quality. As quoted from WPI's website on their sustainability initiative, "WPI is committed to being a campus that incorporates the values of sustainable design in all aspects of site and building design, construction, maintenance and operation procedures." WPI looks to become a leader in sustainability, and the design of this campus center must parallel this message.

7.2.1 LEED v.4 Scorecard

The project checklist below is the result of architectural, structural and mechanical decisions. Due to the stage of design development, certain assumptions were made in order to complete the LEED analysis. The analysis was performed the most updated version of LEED analysis, v.4, which focuses more on materials and performance of mechanical systems. These Assumptions made for the LEED v.4 analysis are listed in the Appendix I: LEED Analysis. The building was determined to meet LEED Silver.

LEED v4 for BD+C: New Construction and Major Renovation

Project Checklist

Gateway Campus Center

3/4/2016 Submittal

Y	?	N			
Y	1		Credi 1	Integrative Process	1
			Location and Transportation	Possible Points:	16
	0	N	Credit 1	LEED for Neighborhood Development Location	16
Y	1		Credit 2	Sensitive Land Protection	1
Y	2		Credit 3	High Priority Site	2
Y	2		Credit 4	Surrounding Density and Diverse Uses	5
Y	3		Credit 5	Access to Quality Transit	5
Y	1		Credit 6	Bicycle Facilities	1
Y	1		Credit 7	Reduced Parking Footprint	1
	0	N	Credit 8	Green Vehicles	1
			Sustainable Sites	Possible Points:	10
Y			Prereq 1	Construction Activity Pollution Prevention	Required
Y	1		Credit 1	Site Assessment	1
Y	2		Credit 2	Site Development--Protect or Restore Habitat	2
Y	1		Credit 3	Open Space	1
Y	1		Credit 4	Rainwater Management	3
	0	N	Credit 5	Heat Island Reduction	2
	0	N	Credit 6	Light Pollution Reduction	1

			Water Efficiency		Possible Points: 11
Y			Prereq 1	Outdoor Water Use Reduction	Required
Y			Prereq 2	Indoor Water Use Reduction	Required
Y			Prereq 3	Building-Level Water Metering	Required
Y	2		Credit 1	Outdoor Water Use Reduction	2
Y	2		Credit 2	Indoor Water Use Reduction	6
Y	1		Credit 3	Cooling Tower Water Use	2
Y	1		Credit 4	Water Metering	1

			Energy and Atmosphere		Possible Points: 33
Y			Prereq 1	Fundamental Commissioning and Verification	Required
Y			Prereq 2	Minimum Energy Performance	Required
Y			Prereq 3	Building-Level Energy Metering	Required
Y			Prereq 4	Fundamental Refrigerant Management	Required
Y	3		Credit 1	Enhanced Commissioning	6
Y	6		Credit 2	Optimize Energy Performance	18
Y	1		Credit 3	Advanced Energy Metering	1
Y	1		Credit 4	Demand Response	2
		N	Credit 5	Renewable Energy Production	3
Y	1		Credit 6	Enhanced Refrigerant Management	1
		N	Credit 7	Green Power and Carbon Offsets	2

			Materials and Resources		Possible Points: 13
Y			Prereq 1	Storage and Collection of Recyclables	Required
Y			Prereq 2	Construction and Demolition Waste Management Planning	Required
Y	5		Credit 1	Building Life-Cycle Impact Reduction	5
Y	1		Credit 2	Building Product Disclosure and Optimization - Environmental Product Declarations	2
Y	1		Credit 3	Building Product Disclosure and Optimization - Sourcing of Raw Materials	2
Y	1		Credit 4	Building Product Disclosure and Optimization - Material Ingredients	2
Y	2		Credit 5	Construction and Demolition Waste Management	2

			Indoor Environmental Quality		Possible Points: 16
Y			Prereq 1	Minimum Indoor Air Quality Performance	Required
Y			Prereq 2	Environmental Tobacco Smoke Control	Required
	1		Credit 1	Enhanced Indoor Air Quality Strategies	2
Y	3		Credit 2	Low-Emitting Materials	3
Y	1		Credit 3	Construction Indoor Air Quality Management Plan	1
Y	1		Credit 4	Indoor Air Quality Assessment	2
Y	1		Credit 5	Thermal Comfort	1
Y	2		Credit 6	Interior Lighting	2
Y	2		Credit 7	Daylight	3
Y	1		Credit 8	Quality Views	1
		N	Credit 9	Acoustic Performance	1

			Innovation		Possible Points: 6

Y	3		Credit 1	Innovation	5
	0	N	Credit 2	LEED Accredited Professional	1

			Regional Priority	Possible Points:	4
	0	N	Credit 1	Regional Priority: Specific Credit	1
	0	N	Credit 2	Regional Priority: Specific Credit	1
	0	N	Credit 3	Regional Priority: Specific Credit	1
	0	N	Credit 4	Regional Priority: Specific Credit	1

59			**Total**	Possible Points:	110

Certified 40 to 49 points Silver 50 to 59 points Gold 60 to 79 points Platinum 80 to 110

7.3 Integration of Multiple Disciplines

The scope of the work completed within this report includes the architectural, structural, and mechanical concepts and designs for the proposed building. Each discipline needed to work together to make the building cohesive. The coordination between the architectural, structural, and mechanical disciplines was crucial to the overall design of the building. This coordination was necessary because all systems within the building must coexist in a predetermined area of space. The use of Revit for coordination was integral to the success of this project. Revit allowed easy coordination of changes between the disciplines. Each discipline was able to work on separate models which could be easily linked to see how they fit together within the building.

7.4 Lessons for the Future

The major lessons from this project revolved around the ideas of constructability and coordination. All design decisions had to be made with multiple factors in mind in order to consider its overall impact on the building. Many design decisions have a direct impact on constructability. There are many situations when a design meets all the requirements, however, causes problems when it is implemented. This includes avoiding significant impacts with other disciplines. Coordination is, therefore, another large factor in the design of a structure. By understanding the general requirements of other disciplines and by constant communication, expensive and time consuming alterations can be avoided. Coordination and constructability work hand in hand in the design of a structure and they are both vitally important to the success of the structure.

7.5 Ideas for Future MQP's

This project encourages further development of the Gateway Campus. As the use of the Gateway Campus grows, more facilities will be required. This could include living spaces, academic buildings, etc. Future MQP groups could focus on developing plans for the further development of the Gateway Campus.

Another idea for a future MQP is to advance with this project by performing and conducting project management tasks. This would include using the building systems designed in this project to create a detailed construction schedule along with a detailed cost estimate. These resources would allow WPI to further examine the feasibility of and resources required for the implementation of the Gateway Campus Center.

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Appendix A: Mechanical Load Calculations

Peak Load Summary

Administration Building							
Skin Load	BTUH	% of Skin	% of Total	Internal Load	BTUH	% of Internal	% of Total
Roof	11611	20%	9%	Light	36140	49%	27%
Wall	9624	17%	7%	People	25750	35%	20%
Glass	36969	64%	28%	Equipment	11650	16%	9%
Total	58203	N/A	44%	Total	73540	N/A	56%
Total RSCL	**131743**	**131.7**	**MBH**	**Total RLCL**	**20600**	**20.6**	**MBH**
Student Building							
Skin Load	BTUHS	% of Skin	% of Total	Internal Load	BTUHS	% of Internal	% of Total
Roof	17028	11%	6%	Light	46980	29%	15%
Wall	10760	7%	3%	People	40250	25%	13%
Glass	121511	81%	39%	Equipment	72031	45%	23%
Total	149299	N/A	48%	Total	159261	N/A	52%
Total RSCL	**308559**	**308.6**	**MBH**	**Total RLCL**	**29200**	**29.2**	**MBH**

Administration Building Part 1

22-Mar-2016			Gateway Campus Center							Roof Type		1	Table A.6						Double Glass	3/8"									
PEAKLOAD			MQP							Susp'd Ceil'g?		1	(1=Y, 0=No)			Floor to Clg Ht	13		Alum w/thermal break										
PEAK			Peak OSA Temp for --				Boston, MA (Logan Airport)			Indoor Temp		76	F			Glass Ht	6		HEAT LOSS DATA										
			40	Degrees N. Lat						Daily Range		16	F						Inside	70	F								
										CLFMED									Outside	0	F								
																										Tin/	Wall	Horiz	Orien-
	Orien-		.... Wall			.... Glass			Room	Roof	Peak	Peak	Total	.... Wall		.... Glass				..... Roof		Heat	Wall	Glass	# of Windows	Tout	LM	LM	tation
Room	tation	Gross Wall	Area	Grp	U	Area	U	SC	Area	U	Mnth	Hour	S&T	CLTD	BTUH	SHGF	CLF	CLTD	BTUH	CLTD	BTUH	Loss	Lgth	Lgth		Corr	Corr	Corr	Code
Room 010	E	136.5	136.5	C	0.05	0	0.35	0.81	127.6	0	9	16	177	26	177	203	0.26	14	0	66	0	478	10.5	0	0	0	-3	-8	90
Room 011	N	195	195	C	0.05	0	0.35	0.81	127.6	0	9	16	78	8	78	30	0.74	14	0	66	0	683	15	0	0	0	-4	-8	1
Room 011	E	136.5	136.5	C	0.05	0	0.35	0.81	0	0	9	16	177	26	177	203	0.26	14	0	66	0	478	10.5	0	0	0	-3	-8	90
Room 012	N	305.5	305.5	C	0.05	0	0.35	0.81	152.34	0	9	16	122	8	122	30	0.74	14	0	66	0	1069	23.5	0	0	0	-4	-8	1
Room 013	-	0	0	C	0.05	0	0.35	0.81	121.43	0	9	16	N/A	N/A	N/A	N/A	N/A	N/A	N/A	66	0	0	0	0	0	0	#VALUE!	-8	#VALUE!
Room 014	-	0	0	C	0.05	0	0.35	0.81	113.58	0	9	16	N/A	N/A	N/A	N/A	N/A	N/A	N/A	66	0	0	0	0	0	0	#VALUE!	-8	#VALUE!
Room 015	-	0	0	C	0.05	0	0.35	0.81	118.89	0	9	16	N/A	N/A	N/A	N/A	N/A	N/A	N/A	66	0	0	0	0	0	0	#VALUE!	-8	#VALUE!
Room 016	S	136.5	136.5	C	0.05	0	0.35	0.81	97.25	0	9	16	205	30	205	200	0.47	14	0	66	0	478	10.5	0	0	0	10	-8	180
Room 017	W	266.5	266.5	C	0.05	0	0.35	0.81	132.56	0	9	16	173	13	173	203	0.50	14	0	66	0	933	20.5	0	0	0	-3	-8	270
Room 018	SE	334.75	334.75	C	0.05	0	0.35	0.81	189.17	0	9	16	536	32	536	226	0.33	14	0	66	0	1172	25.75	0	0	0	4	-8	135
Room 018	SW	208	208	C	0.05	0	0.35	0.81	0	0	9	16	229	22	229	226	0.58	14	0	66	0	728	16	0	0	0	4	-8	225
Room 019	SW	126.75	126.75	C	0.05	0	0.35	0.81	85.56	0	9	16	139	22	139	226	0.58	14	0	66	0	444	9.75	0	0	0	4	-8	225
Assembly 01	E	65	65	C	0.05	0	0.35	0.81	1293.55	0	9	16	85	26	85	203	0.26	14	0	66	0	228	5	0	0	0	-3	-8	90
Assembly 02	N	682.5	682.5	C	0.05	0	0.35	0.81	466.1	0	9	16	273	8	273	30	0.74	14	0	66	0	2389	52.5	0	0	0	-4	-8	1
Assembly 03	S	260	260	C	0.05	0	0.35	0.81	295.19	0	9	16	390	30	390	200	0.47	14	0	66	0	910	20	0	0	0	10	-8	180
Shaft 0	E	188.5	188.5	C	0.05	0	0.35	0.81	71.78	0	9	16	245	26	245	203	0.26	14	0	66	0	660	14.5	0	0	0	-3	-8	90
Shaft 0	S	185.25	185.25	C	0.05	0	0.35	0.81	0	0	9	16	278	30	278	200	0.47	14	0	66	0	648	14.25	0	0	0	10	-8	180

Stair S0	W	269.75	269.75	C	0.05	0	0.35	0.81	163.7	0	9	16	175	13	175	203	0.50	14	0	66	0	944	20.75	0	0	0	-3	-8	270
Stair S0	S	130	130	C	0.05	0	0.35	0.81	0	0	9	16	195	30	195	200	0.47	14	0	66	0	455	10	0	0	0	10	-8	180
Room 101	N	760.5	652.5	C	0.05	108	0.35	0.81	594.43	0	9	16	2732	8	261	30	0.74	14	2471	66	0	4930	58.5	18	6	0	-4	-8	1
Room 102	N	195	195	C	0.05	0	0.35	0.81	88.18	0	9	16	78	8	78	30	0.74	14	0	66	0	683	15	0	0	0	-4	-8	1
Room 102A	W	266.5	266.5	C	0.05	0	0.35	0.81	149.73	0	9	16	173	13	173	203	0.50	14	0	66	0	933	20.5	0	0	0	-3	-8	270
Room 103	-	0	0	C	0.05	0	0.35	0.81	113.5	0	9	16	N/A	N/A	N/A	N/A	N/A	N/A	N/A	66	0	0	0	0	0	0	#VALUE!	-8	#VALUE!
Room 104	-	0	0	C	0.05	0	0.35	0.81	119.89	0	9	16	N/A	N/A	N/A	N/A	N/A	N/A	N/A	66	0	0	0	0	0	0	#VALUE!	-8	#VALUE!
Room 105	SE	334.75	334.75	C	0.05	0	0.35	0.81	189.4	0	9	16	536	32	536	226	0.33	14	0	66	0	1172	25.75	0	0	0	4	-8	135
Room 105	SW	208	208	C	0.05	0	0.35	0.81	0	0	9	16	229	22	229	226	0.58	14	0	66	0	728	16	0	0	0	4	-8	225
Room 106	SW	126.75	126.75	C	0.05	0	0.35	0.81	85.56	0	9	16	139	22	139	226	0.58	14	0	66	0	444	9.75	0	0	0	4	-8	225
Assembly 100	N	234	162	C	0.05	72	0.35	0.81	1601.66	0	9	16	1712	8	65	30	0.74	14	1648	66	0	2331	18	12	4	0	-4	-8	1
Assembly 100	E	344.5	200.5	C	0.05	144	0.35	0.81	0	0	9	16	7123	26	261	203	0.26	14	6862	66	0	4230	26.5	24	8	0	-3	-8	90
Assembly 101	S	383.5	275.5	C	0.05	108	0.35	0.81	376.89	0	9	16	9166	30	413	200	0.47	14	8752	66	0	3610	29.5	18	6	0	10	-8	180
Shaft 1	E	188.5	188.5	C	0.05	0	0.35	0.81	71.78	0	9	16	245	26	245	203	0.26	14	0	66	0	660	14.5	0	0	0	-3	-8	90
Shaft 1	S	185.25	185.25	C	0.05	0	0.35	0.81	0	0	9	16	278	30	278	200	0.47	14	0	66	0	648	14.25	0	0	0	10	-8	180
Stair S1	W	269.75	269.75	C	0.05	0	0.35	0.81	163.7	0	9	16	175	13	175	203	0.50	14	0	66	0	944	20.75	0	0	0	-3	-8	270
Stair S1	S	130	130	C	0.05	0	0.35	0.81	0	0	9	16	195	30	195	200	0.47	14	0	66	0	455	10	0	0	0	10	-8	180
Room 201	-	0	0	C	0.05	0	0.35	0.81	140.56	0.05	9	16	N/A	N/A	N/A	N/A	N/A	N/A	N/A	66	464	492	0	0	0	0	#VALUE!	-8	#VALUE!
Room 202	-	0	0	C	0.05	0	0.35	0.81	120.86	0.05	9	16	N/A	N/A	N/A	N/A	N/A	N/A	N/A	66	399	423	0	0	0	0	#VALUE!	-8	#VALUE!
Room 203	SE	334.75	298.75	C	0.05	36	0.35	0.81	189.4	0.05	9	16	3454	32	478	226	0.33	14	2351	66	625	2591	25.75	6	2	0	4	-8	135
Room 203	SW	208	190	C	0.05	18	0.35	0.81	0	0.05	9	16	2208	22	209	226	0.58	14	1999	66	0	1106	16	3	1	0	4	-8	225
Room 204	SW	126.75	126.75	C	0.05	0	0.35	0.81	85.56	0.05	9	16	422	22	139	226	0.58	14	0	66	282	743	9.75	0	0	0	4	-8	225
Room 205	-	0	0	C	0.05	0	0.35	0.81	119.89	0.05	9	16	N/A	N/A	N/A	N/A	N/A	N/A	N/A	66	396	420	0	0	0	0	#VALUE!	-8	#VALUE!
Room 206	-	0	0	C	0.05	0	0.35	0.81	113.5	0.05	9	16	N/A	N/A	N/A	N/A	N/A	N/A	N/A	66	375	397	0	0	0	0	#VALUE!	-8	#VALUE!
Room 207	S	156	156	C	0.05	0	0.35	0.81	37.02	0.05	9	16	356	30	234	200	0.47	14	0	66	122	676	12	0	0	0	10	-8	180
Room 208	S	234	216	C	0.05	18	0.35	0.81	196.58	0.05	9	16	2431	30	324	200	0.47	14	1459	66	649	1885	18	3	1	0	10	-8	180
Room 209	W	273	273	C	0.05	0	0.35	0.81	129.69	0.05	9	16	605	13	177	203	0.50	14	0	66	428	1409	21	0	0	0	-3	-8	270
Room 210	N	253.5	235.5	C	0.05	18	0.35	0.81	265.56	0.05	9	16	1382	8	94	30	0.74	14	412	66	876	2195	19.5	3	1	0	-4	-8	1

Assembly 201	N	923	779	C	0.05	144	0.35	0.81	1735.3	0.05	9	16	9333	8	312	30	0.74	14	3295	66	5727	12328	71	24	8	0	-4	-8	1
Assembly 201	E	344.5	182.5	C	0.05	162	0.35	0.81	0	0.05	9	16	7957	26	237	203	0.26	14	7720	66	0	4608	26.5	27	9	0	-3	-8	90
Assembly 202	-	0	0	C	0.05	0	0.35	0.81	148.91	0.05	9	16	N/A	N/A	N/A	N/A	N/A	N/A	N/A	66	491	521	0	0	0	0	#VALUE!	-8	#VALUE!
Shaft 3	S	185.25	185.25	C	0.05	0	0.35	0.81	71.78	0.05	9	16	515	30	278	200	0.47	14	0	66	237	900	14.25	0	0	0	10	-8	180
Shaft 3	E	188.5	188.5	C	0.05	0	0.35	0.81	0	0.05	9	16	245	26	245	203	0.26	14	0	66	0	660	14.5	0	0	0	-3	-8	90
Stair S3	S	130	130	C	0.05	0	0.35	0.81	163.7	0.05	9	16	735	30	195	200	0.47	14	0	66	540	1028	10	0	0	0	10	-8	180
Stair S3	W	269.75	269.75	C	0.05	0	0.35	0.81	0	0.05	9	16	175	13	175	203	0.50	14	0	66	0	944	20.75	0	0	0	-3	-8	270

Administration Building Part 2

22-Mar-2016				COOLING LOAD CALCULATION							Indoor T:	76	F										
PEAKLOAD				Gateway Campus Center						Supply Air Temp:		56	F										
LOAD				MQP						Ceiling "U":		0.33											
									Return Plenum (1-Y, 0-N):			1		h out:		37.4	Btu/lb						
									Recessed lights to plenum:			0%		h in:		28.7	Btu/lb						
					S&T	Recessd	Other						Calc'd								Plenum	Initial	Rm Sens
	Orien-	Peak	Peak	Ceil'g	BTUH	Fluor.	Light'g	Appli	Occs. @	Ceil'g	Rm Sens	Calc'd	Plenum	OSA	Rm Latent	TOTAL	Ht Loss	Plenum	Plenum		Wall	Plenum	BTUH
Room	tation	Month	Hour	Area	w/o roof	Lights	Watts	BTUH	250	BTUH	BTUH	CFM	Rise	CFM	BTUH	BTUH	Btuh*	DTavg	DTtemp	Proof	Area	Ht Gain	w/o Ceil
Room 010	E	9	16	127.6	177	127.6		850	2	0	1963	90		0	400	2363	478	0.0	0.0	0.0		0	1963
Room 011	N	9	16	127.6	78	127.6		850	0	0	1363	60			0	1363	683	0.0	0.0	0.0		0	1363
Room 011	E	9	16	0	177	0		0	2	0	677	30			400	1077	478	0.0	0.0	0.0			
Room 012	N	9	16	152.34	122	152.34		850	2	0	1992	90			400	2392	1069	0.0	0.0	0.0		0	1992
Room 013	-	9	16	121.43	0	121.43		850	2	0	1764	80			400	2164	0	0.0	0.0	0.0		0	1764
Room 014	-	9	16	113.58	0	113.58		0	0	0	388	20			0	388	0	0.0	0.0	0.0		0	388
Room 015	-	9	16	118.89	0	118.89		0	0	0	406	20			0	406	0	0.0	0.0	0.0		0	406
Room 016	S	9	16	97.25	205	97.25		0	0	0	537	25			0	537	478	0.0	0.0	0.0		0	537

Room 017	W	9	16	132.56	173	132.56		0	0	0	626	30			0	626	933	0.0	0.0	0.0		0	626
Room 018	SE	9	16	189.17	536	189.17		1000	0	0	2181	100			0	2181	1172	0.0	0.0	0.0		0	2181
Room 018	SW	9	16	0	229	0		0	0	0	229	10			0	229	728	0.0	0.0	0.0		0	229
Room 019	SW	9	16	85.56	139	85.56		0	0	0	431	20			0	431	444	0.0	0.0	0.0		0	431
Assembly 01	E	9	16	1293.55	85	1293.55		1000	20	0	10499	475			4000	14499	228	0.0	0.0	0.0		0	10499
Assembly 02	N	9	16	466.1	273	466.1		0	5	0	3114	140			1000	4114	2389	0.0	0.0	0.0		0	3114
Assembly 03	S	9	16	295.19	390	295.19		0	0	0	1397	65			0	1397	910	0.0	0.0	0.0		0	1397
Shaft 0	E	9	16	71.78	245	71.78		0	0	0	490	20			0	490	660	0.0	0.0	0.0		0	490
Shaft 0	S	9	16	0	278	0		0	0	0	278	15			0	278	648	0.0	0.0	0.0		0	278
Stair S0	W	9	16	163.7	175	163.7		0	0	0	734	35			0	734	944	0.0	0.0	0.0		0	734
Stair S0	S	9	16	0	195	0		0	0	0	195	10			0	195	455	0.0	0.0	0.0		0	195
Room 101	N	9	16	594.43	2732	594.43		1000	5	0	7011	320			1000	8011	4930	0.0	0.0	0.0		0	7011
Room 102	N	9	16	88.18	78	88.18		0	0	0	379	15			0	379	683	0.0	0.0	0.0		0	379
Room 102A	W	9	16	149.73	173	149.73		0	0	0	684	30			0	684	933	0.0	0.0	0.0		0	684
Room 103	-	9	16	113.5	0	113.5		0	0	0	387	20			0	387	0	0.0	0.0	0.0		0	387
Room 104	-	9	16	119.89	0	119.89		0	0	0	409	20			0	409	0	0.0	0.0	0.0		0	409
Room 105	SE	9	16	189.4	536	189.4		1000	2	0	2682	120			400	3082	1172	0.0	0.0	0.0		0	2682
Room 105	SW	9	16	0	229	0		0	0	0	229	10			0	229	728	0.0	0.0	0.0		0	229
Room 106	SW	9	16	85.56	139	85.56		0	0	0	431	20			0	431	444	0.0	0.0	0.0		0	431
Assembly 100	N	9	16	1601.66	1712	1601.66		0	20	0	12179	555			4000	16179	2331	0.0	0.0	0.0		0	12179
Assembly 100	E	9	16	0	7123	0		0	0	0	7123	325			0	7123	4230	0.0	0.0	0.0		0	7123
Assembly 101	S	9	16	376.89	9166	376.89		0	10	0	12952	590			2000	14952	3610	0.0	0.0	0.0		0	12952
Shaft 1	E	9	16	71.78	245	71.78		0	0	0	490	20			0	490	660	0.0	0.0	0.0		0	490
Shaft 1	S	9	16	0	278	0		0	0	0	278	15			0	278	648	0.0	0.0	0.0		0	278
Stair S1	W	9	16	163.7	175	163.7		0	0	0	734	35			0	734	944	0.0	0.0	0.0		0	734
Stair S1	S	9	16	0	195	0		0	0	0	195	10			0	195	455	0.0	0.0	0.0		0	195
Room 201	-	9	16	140.56	-464	140.56		850	1	0	1116	50			200	1780	492	4.2	8.4	463.8		464	1116
Room 202	-	9	16	120.86	-399	120.86		850	1	0	1114	50			200	1712	423	3.6	7.3	398.8		399	1114

Room 203	SE	9	16	189.4	2829	189.4		850	1	0	4576	210			200	5401	2591	1.4	2.7	625.0		625	4576
Room 203	SW	9	16	0	2208	0		0	0	0	2208	100			0	2208	1106	0.0	0.0	0.0		0	2208
Room 204	SW	9	16	85.56	139	85.56		0	0	0	431	20			0	714	743	6.4	12.8	282.3		282	431
Room 205	-	9	16	119.89	-396	119.89		0	0	0	14	0			0	409	420	#DIV/0!	#DIV/0!	395.6		396	14
Room 206	-	9	16	113.5	-375	113.5		0	0	0	13	0			0	387	397	#DIV/0!	#DIV/0!	374.6		375	13
Room 207	S	9	16	37.02	234	37.02		0	0	0	360	15			0	483	676	3.7	7.4	122.2		122	360
Room 208	S	9	16	196.58	1783	196.58		850	5	0	4554	205			1000	6202	1885	1.4	2.9	648.7		649	4554
Room 209	W	9	16	129.69	177	129.69		0	0	0	620	30			0	1048	1409	6.5	13.0	428.0		428	620
Room 210	N	9	16	265.56	506	265.56		850	5	0	3512	160			1000	5389	2195	2.5	5.0	876.3		876	3512
Assembly 201	N	9	16	1735.33	3607	1735.33		0	20	0	14529	660			4000	24256	12328	3.9	7.9	5726.6		5727	14529
Assembly 201	E	9	16	0	7957	0		0	0	0	7957	360			0	7957	4608	0.0	0.0	0.0		0	7957
Assembly 202	-	9	16	148.91	-491	148.91		0	0	0	17	0			0	508	521	#DIV/0!	#DIV/0!	491.4		491	17
Shaft 3	S	9	16	71.78	278	71.78		0	0	0	523	25			0	760	900	4.3	8.6	236.9		237	523
Shaft 3	E	9	16	0	245	0		0	0	0	245	10			0	245	660	0.0	0.0	0.0		0	245
Stair S3	S	9	16	163.7	195	163.7		0	0	0	754	35			0	1294	1028	7.0	14.0	540.2		540	754
Stair S3	W	9	16	0	175	0		0	0	0	175	10			0	175	944	0.0	0.0	0.0		0	175

Student Building Part 1

23-Mar-2016			Project Identification 1							Roof Type		1	Table A.6						Double Glass	3/8"									
PEAKLOAD			Project Identification 2							Susp'd Ceil'g?		1	(1=Y, 0=No)			Floor to Clg Ht	13		Alum w/thermal break										
PEAK			Peak OSA Temp for --				Boston, MA (Logan Airport)			Indoor Temp		76	F			Glass Ht	6		HEAT LOSS DATA										
			40	Degrees N. Lat						Daily Range		16	F						Inside	70	F								
										CLFM ED									Outside	0	F								
																										Tin /	Wall	Horiz	Orien-
	Orien-		.... Wall			.... Glass			Room	Roof	Peak	Peak	Total	.... Wall		.... Glass				..... Roof		Heat	Wall	Glass	# of Windows	To ut	LM	LM	tation
Room	tation	Gross Wall	Area	Grp	U	Area	U	SC	Area	U	Mnth	Hour	S&T	CLTD	BTUH	SHGF	CLF	CLTD	BTUH	CLTD	BTUH	Loss	Lgth	Lgth		Corr	Corr	Corr	Code

Room 107	N	422.5	314.5	C	0.05	108	0.35	0.81	458.21	0	9	16	2597	8	126	30	0.74	14	2471	66	0	3747	32.5	18	6	0	-4	-8	1
Room 107	W	416	236	C	0.05	180	0.35	0.81	0	0	9	16	15834	13	153	203	0.50	14	15681	66	0	5236	32	30	10	0	-3	-8	270
Room 108	NE	214.5	214.5	C	0.05	0	0.35	0.81	102.97	0	9	16	182	17	182	87	0.26	14	0	66	0	751	16.5	0	0	0	-5	-8	45
Room 108	NW	214.5	214.5	C	0.05	0	0.35	0.81	0	0	9	16	86	8	86	87	0.42	14	0	66	0	751	16.5	0	0	0	-5	-8	315
Room 109	-	0	0	C	0.05	0	0.35	0.81	78.14	0	9	16	N/A	N/A	N/A	N/A	N/A	N/A	N/A	66	0	0	0	0	0	0	#VALUE!	-8	#VALUE!
Room 110	N	344.5	308.5	C	0.05	36	0.35	0.81	356.29	0	9	16	947	8	123	30	0.74	14	824	66	0	1962	26.5	6	2	0	-4	-8	1
Room 111	-	0	0	C	0.05	0	0.35	0.81	119.73	0	9	16	N/A	N/A	N/A	N/A	N/A	N/A	N/A	66	0	0	0	0	0	0	#VALUE!	-8	#VALUE!
Room 112	E	468	468	C	0.05	0	0.35	0.81	386.89	0	9	16	608	26	608	203	0.26	14	0	66	0	1638	36	0	0	0	-3	-8	90
Room 113	-	0	0	C	0.05	0	0.35	0.81	222.31	0	9	16	N/A	N/A	N/A	N/A	N/A	N/A	N/A	66	0	0	0	0	0	0	#VALUE!	-8	#VALUE!
Room 114	S	409.5	409.5	C	0.05	0	0.35	0.81	208.85	0	9	16	614	30	614	200	0.47	14	0	66	0	1433	31.5	0	0	0	10	-8	180
Shaft 2	N	58.5	58.5	C	0.05	0	0.35	0.81	14.21	0	9	16	23	8	23	30	0.74	14	0	66	0	205	4.5	0	0	0	-4	-8	1
Stair S2	N	253.5	253.5	C	0.05	0	0.35	0.81	154.86	0	9	16	101	8	101	30	0.74	14	0	66	0	887	19.5	0	0	0	-4	-8	1
Stair S2	E	143	143	C	0.05	0	0.35	0.81	0	0	9	16	186	26	186	203	0.26	14	0	66	0	501	11	0	0	0	-3	-8	90
Assembly 103	S	975	813	C	0.05	162	0.35	0.81	2781.4	0	9	16	14348	30	1220	200	0.47	14	13128	66	0	6815	75	27	9	0	10	-8	180
Assembly 103	W	240.5	150.5	C	0.05	90	0.35	0.81	0	0	9	16	7938	13	98	203	0.50	14	7840	66	0	2732	18.5	15	5	0	-3	-8	270
Assembly 104	E	52	52	C	0.05	0	0.35	0.81	66.34	0	9	16	68	26	68	203	0.26	14	0	66	0	182	4	0	0	0	-3	-8	90
Room 211	W	416	236	C	0.05	180	0.35	0.81	224.68	0	9	16	15834	13	153	203	0.50	14	15681	66	0	5236	32	30	10	0	-3	-8	270
Room 212	N	422.5	314.5	C	0.05	108	0.35	0.81	188.69	0	9	16	2597	8	126	30	0.74	14	2471	66	0	3747	32.5	18	6	0	-4	-8	1
Room 213	NE	214.5	214.5	C	0.05	0	0.35	0.81	102.97	0	9	16	182	17	182	87	0.26	14	0	66	0	751	16.5	0	0	0	-5	-8	45
Room 213	NW	214.5	214.5	C	0.05	0	0.35	0.81	0	0	9	16	86	8	86	87	0.42	14	0	66	0	751	16.5	0	0	0	-5	-8	315
Room 214	-	0	0	C	0.05	0	0.35	0.81	78.14	0	9	16	N/A	N/A	N/A	N/A	N/A	N/A	N/A	66	0	0	0	0	0	0	#VALUE!	-8	#VALUE!
Room 215	N	344.5	308.5	C	0.05	36	0.35	0.81	314.33	0	9	16	947	8	123	30	0.74	14	824	66	0	1962	26.5	6	2	0	-4	-8	1
Room 216	E	468	468	C	0.05	0	0.35	0.81	154.86	0	9	16	608	26	608	203	0.26	14	0	66	0	1638	36	0	0	0	-3	-8	90
Room 217	-	0	0	C	0.05	0	0.35	0.81	222.31	0	9	16	N/A	N/A	N/A	N/A	N/A	N/A	N/A	66	0	0	0	0	0	0	#VALUE!	-8	#VALUE!
Room 218	S	403	403	C	0.05	0	0.35	0.81	208.85	0	9	16	605	30	605	200	0.47	14	0	66	0	1411	31	0	0	0	10	-8	180
Room 219	S	377	359	C	0.05	18	0.35	0.81	191.66	0	9	16	1997	30	539	200	0.47	14	1459	66	0	1698	29	3	1	0	10	-8	180
Shaft 4	N	58.5	58.5	C	0.05	0	0.35	0.81	14.21	0	9	16	23	8	23	30	0.74	14	0	66	0	205	4.5	0	0	0	-4	-8	1
Stair S4	N	253.5	253.5	C	0.05	0	0.35	0.81	154.86	0	9	16	101	8	101	30	0.74	14	0	66	0	887	19.5	0	0	0	-4	-8	1

Stair S4	E	143	143	C	0.05	0	0.35	0.81	0	0	9	16	186	26	186	203	0.26	14	0	66	0	501	11	0	0	0	-3	-8	90
Assembly 203	W	247	139	C	0.05	108	0.35	0.81	2573.1	0	9	16	9499	13	90	203	0.50	14	9408	66	0	3133	19	18	6	0	-3	-8	270
Assembly 203	S	598	472	C	0.05	126	0.35	0.81	0	0	9	16	10919	30	708	200	0.47	14	10211	66	0	4739	46	21	7	0	10	-8	180
Assembly 204	E	52	52	C	0.05	0	0.35	0.81	108.15	0	9	16	68	26	68	203	0.26	14	0	66	0	182	4	0	0	0	-3	-8	90
Assembly 205	-	0	0	C	0.05	0	0.35	0.81	30.68	0	9	16	N/A	N/A	N/A	N/A	N/A	N/A	N/A	66	0	0	0	0	0	0	#VALUE!	-8	#VALUE!
Room 301	N	344.5	308.5	C	0.05	36	0.35	0.81	357.22	0.06	9	16	2362	8	123	30	0.74	14	824	66	1415	3462	26.5	6	2	0	-4	-8	1
Room 301	E	520	520	C	0.05	0	0.35	0.81	0	0.06	9	16	676	26	676	203	0.26	14	0	66	0	1820	40	0	0	0	-3	-8	90
Room 302	-	0	0	C	0.05	0	0.35	0.81	222.31	0.06	9	16	N/A	N/A	N/A	N/A	N/A	N/A	N/A	66	880	934	0	0	0	0	#VALUE!	-8	#VALUE!
Room 303	S	409.5	409.5	C	0.05	0	0.35	0.81	208.85	0.06	9	16	1441	30	614	200	0.47	14	0	66	827	2310	31.5	0	0	0	10	-8	180
Room 304	N	422.5	314.5	C	0.05	108	0.35	0.81	458.21	0.06	9	16	4412	8	126	30	0.74	14	2471	66	1815	5671	32.5	18	6	0	-4	-8	1
Room 304	W	416	236	C	0.05	180	0.35	0.81	0	0.06	9	16	15834	13	153	203	0.50	14	15681	66	0	5236	32	30	10	0	-3	-8	270
Room 305	NW	214.5	214.5	C	0.05	0	0.35	0.81	102.97	0.06	9	16	494	8	86	87	0.42	14	0	66	408	1183	16.5	0	0	0	-5	-8	315
Room 305	NE	214.5	214.5	C	0.05	0	0.35	0.81	0	0.06	9	16	182	17	182	87	0.26	14	0	66	0	751	16.5	0	0	0	-5	-8	45
Room 306	-	0	0	C	0.05	0	0.35	0.81	0	0.06	9	16	N/A	N/A	N/A	N/A	N/A	N/A	N/A	66	0	0	0	0	0	0	#VALUE!	-8	#VALUE!
Assembly 301	S	968.5	806.5	C	0.05	162	0.35	0.81	2781.4	0.06	9	16	25352	30	1210	200	0.47	14	13128	66	11014	18474	74.5	27	9	0	10	-8	180
Assembly 301	W	247	139	C	0.05	108	0.35	0.81	0	0.06	9	16	9499	13	90	203	0.50	14	9408	66	0	3133	19	18	6	0	-3	-8	270
Stair S5	N	253.5	253.5	C	0.05	0	0.35	0.81	154.86	0.06	9	16	715	8	101	30	0.74	14	0	66	613	1538	19.5	0	0	0	-4	-8	1
Stair S5	E	143	143	C	0.05	0	0.35	0.81	0	0.06	9	16	186	26	186	203	0.26	14	0	66	0	501	11	0	0	0	-3	-8	90
Shaft 5	N	58.5	58.5	C	0.05	0	0.35	0.81	14.21	0.06	9	16	80	8	23	30	0.74	14	0	66	56	264	4.5	0	0	0	-4	-8	1

Student Building Part 2

23-Mar-2016				COOLING LOAD CALCULATION							Indoor T:	76	F										
PEAKLOAD				Gateway Campus Center						Supply Air Temp:		56	F										
LOAD				MQP						Ceiling "U":		0.33											
									Return Plenum (1-Y, 0-N):			1		h out:		37.4	Btu/lb						

Room	Orien-tation	Peak Month	Peak Hour	Ceil'g Area	S&T BTUH w/o roof	Recessd Fluor. Lights	Other Light'g Watts	Appli BTUH	Occs. @ 250	Ceil'g BTUH	Rm Sens BTUH	Calc'd CFM	Calc'd Plenum Rise	OSA CFM	Rm Latent BTUH	TOTAL BTUH	Ht Loss Btuh*	Plenum DTavg	Plenum DTtemp	Proof	Plenum Wall Area	Initial Plenum Ht Gain	Rm Sens BTUH w/o Ceil
									Recessed lights to plenum:			0%		h in:		28.7	Btu/lb						
Room 107	N	9	16	458.21	2597	458.21		0	5	0	5411	245			1000	6411	3747	0.0	0.0	0.0		0	5411
Room 107	W	9	16	0	15834	0		0	5	0	17084	775			1000	18084	5236	0.0	0.0	0.0		0	17084
Room 108	NE	9	16	102.97	182	102.97		1000	0	0	1534	70			0	1534	751	0.0	0.0	0.0		0	1534
Room 108	NW	9	16	0	86	0		0	0	0	86	5			0	86	751	0.0	0.0	0.0		0	86
Room 109	-	9	16	78.14	0	78.14		0	0	0	267	10			0	267	0	0.0	0.0	0.0		0	267
Room 110	N	9	16	356.29	947	356.29		55131	5	0	58544	2660			1000	59544	1962	0.0	0.0	0.0		0	58544
Room 111	-	9	16	119.73	0	119.73		0	0	0	409	20			0	409	0	0.0	0.0	0.0		0	409
Room 112	E	9	16	386.89	608	386.89		0	0	0	1929	90			0	1929	1638	0.0	0.0	0.0		0	1929
Room 113	-	9	16	222.31	0	222.31		0	0	0	759	35			0	759	0	0.0	0.0	0.0		0	759
Room 114	S	9	16	208.85	614	208.85		0	0	0	1327	60			0	1327	1433	0.0	0.0	0.0		0	1327
Shaft 2	N	9	16	14.21	23	14.21		0	0	0	72	5			0	72	205	0.0	0.0	0.0		0	72
Stair S2	N	9	16	154.86	101	154.86		0	0	0	630	30			0	630	887	0.0	0.0	0.0		0	630
Stair S2	E	9	16	0	186	0		0	0	0	186	10			0	186	501	0.0	0.0	0.0		0	186
Assembly 103	S	9	16	2781.37	14348	2781.37		10000	20	0	38841	1765			4000	42841	6815	0.0	0.0	0.0		0	38841
Assembly 103	W	9	16	0	7938	0		0	30	0	15438	700			6000	21438	2732	0.0	0.0	0.0		0	15438
Assembly 104	E	9	16	66.34	68	66.34		0	0	0	294	15			0	294	182	0.0	0.0	0.0		0	294
Room 211	W	9	16	224.68	15834	224.68		850	4	0	18451	840			800	19251	6597	0.0	0.0	0.0		0	18451
Room 212	N	9	16	188.69	2597	188.69		850	4	0	5091	230			800	5891	4721	0.0	0.0	0.0		0	5091
Room 213	NE	9	16	102.97	182	102.97		1000	0	0	1534	70			0	1534	946	0.0	0.0	0.0		0	1534
Room 213	NW	9	16	0	86	0		0	0	0	86	5			0	86	946	0.0	0.0	0.0		0	86
Room 214	-	9	16	78.14	0	78.14		0	0	0	267	10			0	267	0	0.0	0.0	0.0		0	267
Room 215	N	9	16	314.33	947	314.33		850	10	0	5370	245			2000	7370	2472	0.0	0.0	0.0		0	5370
Room 216	E	9	16	154.86	608	154.86		500	4	0	2637	120			800	3437	2064	0.0	0.0	0.0		0	2637

Room 217	-	9	16	222.31	0	222.31		0	0	0	759	35			0	759	0	0.0	0.0	0.0		0	759
Room 218	S	9	16	208.85	605	208.85		0	0	0	1317	60			0	1317	1777	0.0	0.0	0.0		0	1317
Room 219	S	9	16	191.66	1997	191.66		850	4	0	4501	205			800	5301	2139	0.0	0.0	0.0		0	4501
Shaft 4	N	9	16	14.21	23	14.21		0	0	0	72	5			0	72	258	0.0	0.0	0.0		0	72
Stair S4	N	9	16	154.86	101	154.86		0	0	0	630	30			0	630	1118	0.0	0.0	0.0		0	630
Stair S4	E	9	16	0	186	0		0	0	0	186	10			0	186	631	0.0	0.0	0.0		0	186
Assembly 203	W	9	16	2573.05	9499	2573.05		0	5	0	19531	890			1000	20531	3947	0.0	0.0	0.0		0	19531
Assembly 203	S	9	16	0	10919	0		0	10	0	13419	610			2000	15419	5971	0.0	0.0	0.0		0	13419
Assembly 204	E	9	16	108.15	68	108.15		0	0	0	437	20			0	437	229	0.0	0.0	0.0		0	437
Assembly 205	-	9	16	30.68	0	30.68		0	0	0	105	5			0	105	0	0.0	0.0	0.0		0	105
Room 301	N	9	16	357.22	947	357.22		0	5	0	3416	155			1000	5831	4362	4.1	8.3	1414.6		1415	3416
Room 301	E	9	16	0	676	0		0	0	0	676	30			0	676	2293	0.0	0.0	0.0		0	676
Room 302	-	9	16	222.31	-880	222.31		0	0	0	-122	0			0	759	1176	#DIV/0!	#DIV/0!	880.3		880	-122
Room 303	S	9	16	208.85	614	208.85		0	0	0	1327	60			0	2154	2911	6.3	12.5	827.0		827	1327
Room 304	N	9	16	458.21	2597	458.21		0	10	0	6661	305			2000	10475	7146	2.7	5.4	1814.5		1815	6661
Room 304	W	9	16	0	15834	0		0	5	0	17084	775			1000	18084	6597	0.0	0.0	0.0		0	17084
Room 305	NW	9	16	102.97	86	102.97		1000	0	0	1437	65			0	1845	1491	2.9	5.7	407.8		408	1437
Room 305	NE	9	16	0	182	0		0	0	0	182	10			0	182	946	0.0	0.0	0.0		0	182
Room 306	-	9	16	0	0	0		0	0	0	0	0			0	0	0	#DIV/0!	#DIV/0!	0.0		0	0
Assembly 301	S	9	16	2781.37	14338	2781.37		0	10	0	26331	1195			2000	39345	23277	4.2	8.4	11014.2		11014	26331
Assembly 301	W	9	16	0	9499	0		0	10	0	11999	545			2000	13999	3947	0.0	0.0	0.0		0	11999
Stair S5	N	9	16	154.86	101	154.86		0	0	0	630	30			0	1243	1937	9.3	18.6	613.2		613	630
Stair S5	E	9	16	0	186	0		0	0	0	186	10			0	186	631	0.0	0.0	0.0		0	186
Shaft 5	N	9	16	14.21	23	14.21		0	0	0	72	5			0	128	333	5.1	10.2	56.3		56	72

Appendix B: Structural Grid Options

Administration Building

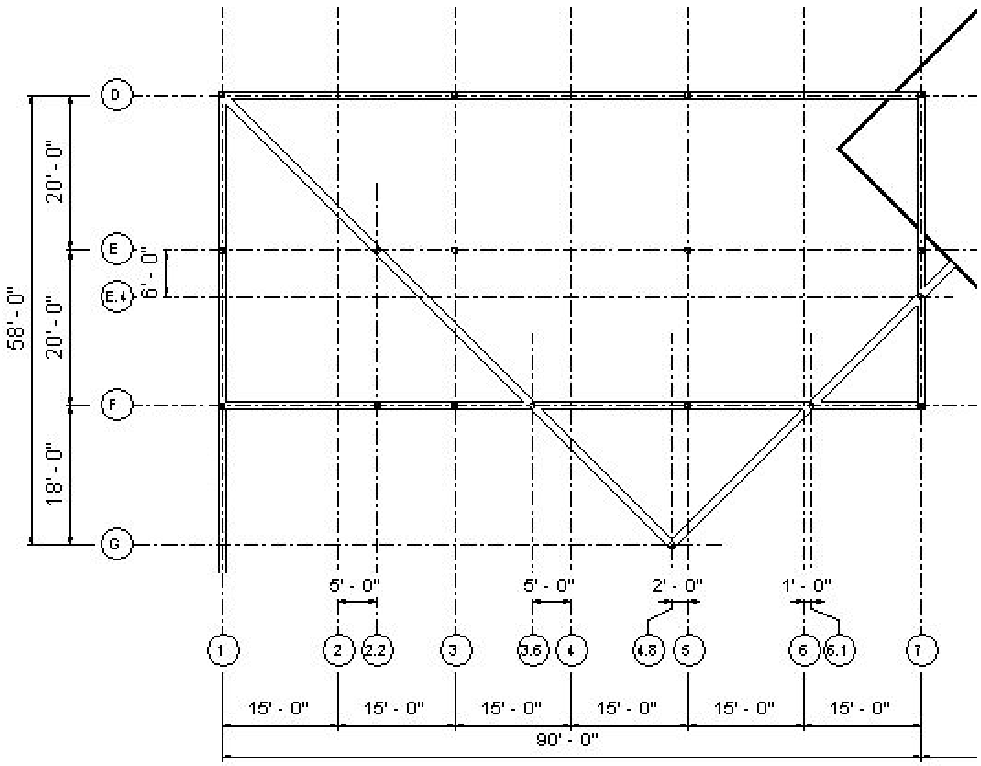


Figure 65: Administration building rejected grid option

The grid option shown in Figure 65 was rejected due to an excess of columns. The inspiration for this layout was to focus the columns in the exterior wall and the brace wall. This would allow a very open floor plan. However, due to the large number of offices and small rooms located in this building, columns located in the interior of the building could be easily hidden by interior walls. This led the team to select the grid option shown in Figure 22, because it allowed for less irregular bay shapes while still avoiding impact on the floor plan.

Student Building

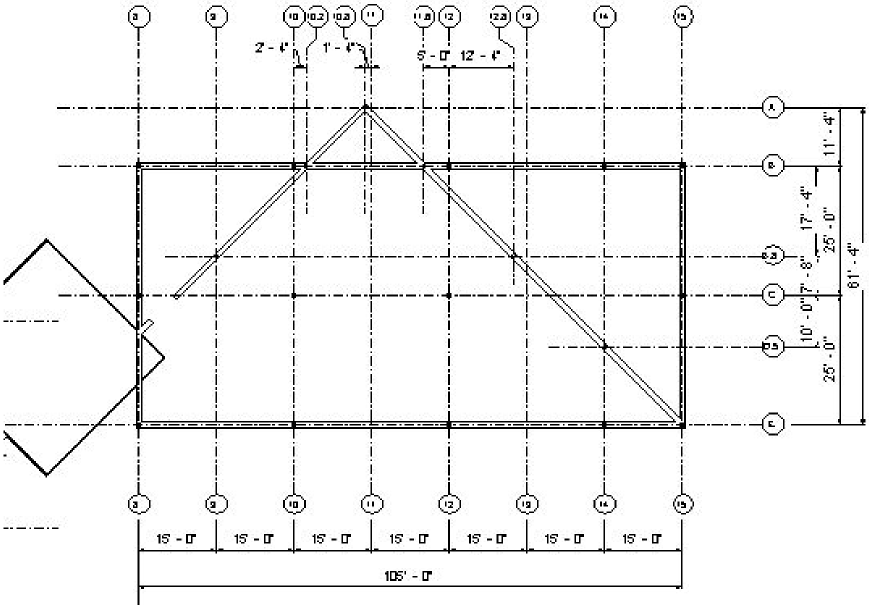


Figure 66: Rejected grid layout for the Student building

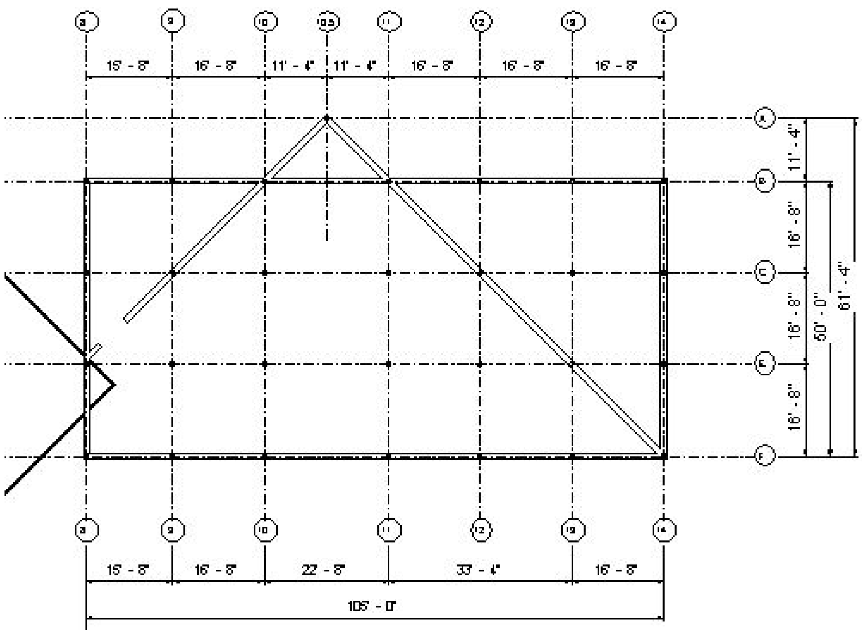


Figure 67: Rejected grid layout with extra columns for the Student building

The grid options shown in Figure 66 and Figure 67 for the Student building were designed to reduce the spans of the girders located in the braced frame. The initial concern was that these girders would get exceedingly large, causing the interior wall to be unacceptably thick. The grid option in Figure 66 uses fewer columns than that of Figure 67; however, it also causes more irregular bay configurations and longer spans. To determine if the braced frame girder would be an acceptable size, preliminary sizing was performed. It was determined that these girders could span longer than in these grid options without creating the need for an excessively wide interior wall around the braced frame. Therefore, the grid option shown in Figure 23 was determined to allow a low amount of columns, more typical bay configurations, and reasonably sized girders. Our team selected the grid layout shown in Figure 23.

Appendix C: Structural Load Calculations

The lateral loads were calculated based on *ASCE 7-05*. These loads are dependent on the building location. The Massachusetts Amendments to the *2009 IBC* provides lateral coefficients specific to towns in Massachusetts. The values for Worcester were used in the calculation procedure detailed in *ASCE 7-05*.

Tributary Width

Tributary width is the area of the floor that the member supports. Usually, this value can be calculated as half the distance from the member to a member of the same type. This process is repeated for both sides of the member and the numbers are added together to find the tributary width. Examples of tributary width can be seen in Figure 68 and Figure 69.

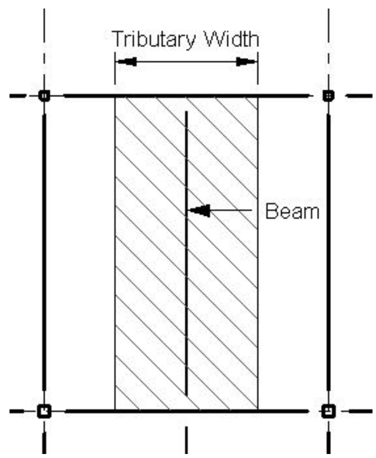


Figure 68: Typical tributary width for a beam

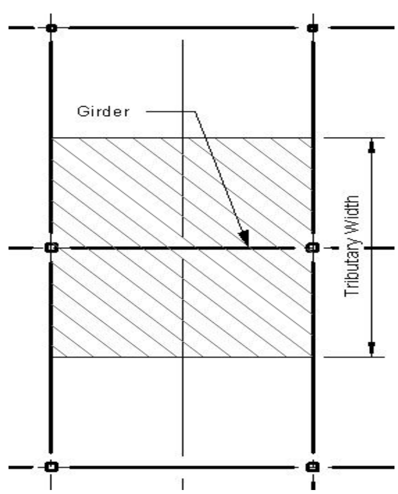


Figure 69: Typical tributary width for a girder

Determining the tributary area for a column is similar to that for a beam except that it occurs on all sides of the column. An example of column tributary area can be seen in Figure 70.

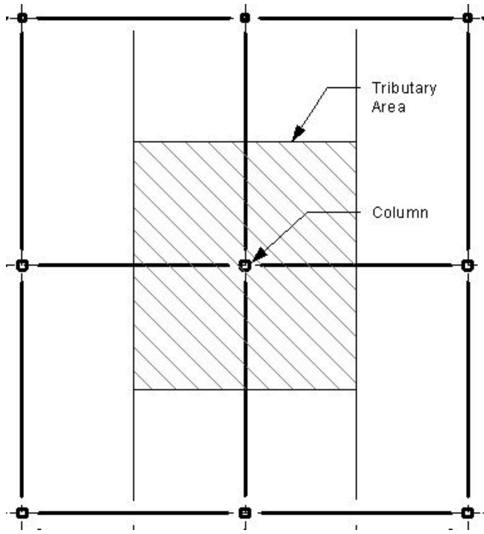


Figure 70: Typical tributary area for a column

Snow Loads

Snow loads were determined using *ASCE 7-05 Chapter 7*. The procedure for designing a flat roof snow load of a building is as follows:

Step Description	Value
1. Determine the ground snow load, p_g, for the specific location of the building. a. This value is taken from the *MA Building Code* (MA State Board of Building Regulations and Standards, 2010).	p_g = 55 psf
2. Determine the exposure factor, C_e, using *ASCE 7-05, Table 7-2*, based on the surrounding terrain.	C_e = 0.9
3. Determine the thermal factor, C_t, using *ASCE 7-05*, *Table 7-3*, based on the thermal condition of the building.	C_t = 1.0
4. Determine the importance factor, I, using ASCE *7-05, Table 7-4*, based on the building occupancy category.	I = 1.1
5. Calculate the flat roof snow load, p_f, using the equation $p_f = 0.7C_eC_tIp_g$	p_f = 38.1 psf (40 psf was used)
6. If necessary calculate snow drift, sliding snow, and unbalanced snow load using *ASCE 7-05 Chapter 7* (American Society of Civil Engineers, 2006).	

Wind Loads

Wind loads were calculated for this project using *ASCE 7-05 Chapter 6*. Since the conceptual Gateway Campus Center is a simple diaphragm, low-rise, enclosed, regular-shaped, and rigid building, and has a roof with a slope less than 45 degrees, the simplified procedure could be used to calculate the wind force on the Main Wind-Force Resisting Systems (MWFRS). The simplified procedure allows simple calculation on the various exterior zones of a building. The different zones can be seen in Figure 71. The steps for the simplified procedure are as follows (American Society of Civil Engineers, 2006):

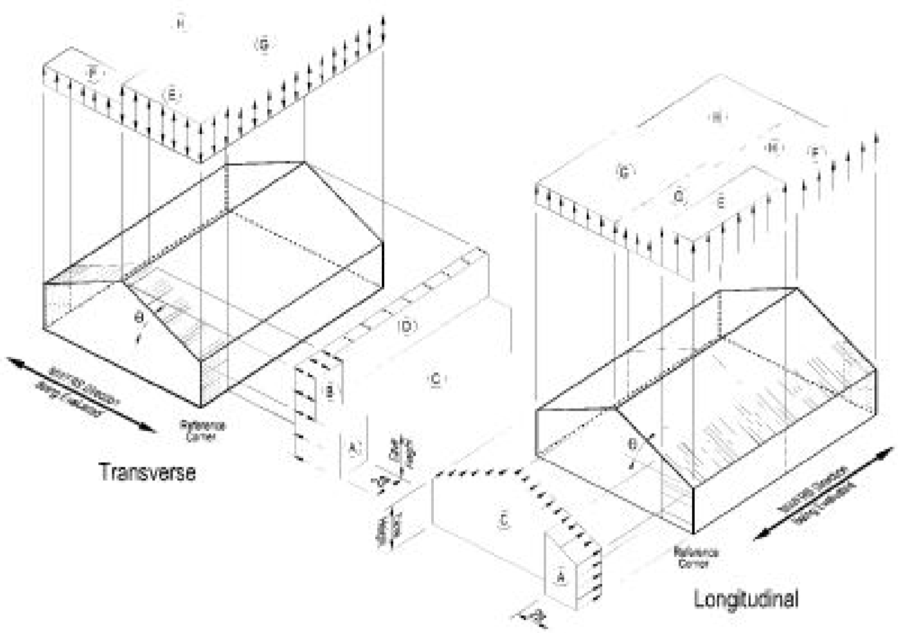


Figure 71: ASCE 7-05 defined wind zones used for wind load determination

Step Description	Administration	Student
1. Determine the basic wind speed (in mph), V, for the building location. a. This number is given in the *MA Building Code* (MA State Board of Building Regulations and Standards, 2010).	V = 100 mph	V = 100 mph
2. Determine the wind importance factor, I_W.	$I_w = 1.15$	$I_w = 1.15$

a. This value is found in *ASCE 7-05 Chapter 6, Table 6-1,* based on the building occupancy category.		
3. Determine the topographic factor, K_{zt}. a. This value can be set to one if there are no hills or ridges directly adjacent to the building.	$K_{zt} = 1$	$K_{zt} = 1$
4. Determine the exposure category based on *ASCE 7-05, Section 6.5.6.3*. a. This category depends on the area surrounding the building, including vegetation, topography, and constructed facilities.	B	B
5. Determine the height and exposure coefficient, λ. a. This value is determined from *ASCE 7-05, Figure 6-2,* based on mean roof height and exposure category.	$\lambda = 1$	$\lambda = 1.082$
6. Determine the simplified design wind pressure height of 30 feet and an importance factor of one, p_{s30}, for each zone of the building. a. These values can be found in *ASCE 7-05, Figure 6-2,* based on basic wind speed and roof angle.	p_{s30} = 15.9 psf (zone A) p_{s30} = 10.5 psf (zone C)	p_{s30} = 15.9 psf (zone A) p_{s30} = 10.5 psf (zone C)
7. Adjust p_{s30} using the equation $p_s = \lambda I_W K_{zt} p_{s30}$ for each zone of the building.	p_s = 18.29 psf (zone A) p_s = 12.08 psf (zone C)	p_s = 19.78 psf (zone A) p_s = 13.07 psf (zone A)
8. Calculate the width of zone A, which is equal to 2a. a. Where a = .1*least horizontal dimension of the building or 0.4*height of the building, whichever is smaller, but not less than 3 feet or .04*least horizontal dimension of the building.	Width of A = 11.6’	Width of A = 12.266’
9. Determine the area of each of the zones in both the transverse and longitudinal direction. Note that both the	Area of Zone A= 603.2 ft^2	Area of Zone A= 956.8 ft^2

transverse and longitudinal directions have two A zones, one at each wall end.	Area of Zone C= 1736.8 ft^2	Area of Zone C= 3138.3 ft^2
10. Multiply the p_s value for each zone by that respective zone's area to determine the wind force, in pounds, contributed from that zone. Add all the forces together to determine the total wind force. Do this for both the longitudinal and transverse directions to determine the critical case (American Society of Civil Engineers, 2006).	Total Wind Force = 32 kips	Total Wind Force = 60 kips

Seismic Loads

Seismic Loads for this project were calculated using *ASCE 7-05 Chapters 11 and 12*. The procedure used by our group was the Equivalent Lateral Force Procedure, and is as follows:

Step Description	Administration	Student
1. Determine the mapped maximum considered earthquake (MEC), 5 percent damped, spectral response acceleration parameter at short periods, S_S, and mapped MCE, 5 percent damped, spectral response acceleration parameter at a period of one second, S_1. a. These coefficients are taken from the *MA Building Code* (MA State Board of Building Regulations and Standards, 2010).	S_s = 0.24 S_1 = 0.067	S_s = 0.24 S_1 = 0.067
2. Based on site soil properties, found from doing a geotechnical investigation, determine the site class.	Site Class D	Site Class D
3. Determine site coefficients F_a and F_v using *ASCE 7-05 Chapter 11, Tables 11.4-1 and 11.4-2*, respectively. a. F_a is determined based on S_S value and the site class designation. b. F_V is determined based on S_1 value and the site class designation.	F_a = 1.6 F_v = 2.4	F_a = 1.6 F_v = 2.4
4. Calculate the MCE spectral response acceleration for short periods, S_{MS}, and at a period of one second, S_{M1}, using the following equations: a. $S_{MS} = F_a S_S$ b. $S_{M1} = F_V S_1$	S_{MS} = 0.384 S_{M1} = 0.1608	S_{MS} = 0.384 S_{M1} = 0.1608
5. Calculate the design earthquake spectral response acceleration parameter at short period, S_{DS}, and at a period of one second, S_{D1}, based on the following equations:	S_{DS} = 0.256 S_{D1} = 0.1072	S_{DS} = 0.256 S_{D1} = 0.1072

a. $S_{DS} = \frac{2}{3} S_{MS}$ b. $S_{D1} = \frac{2}{3} S_{M1}$		
6. Determine the seismic importance factor, I a. This value is determined from *ASCE 7-05, Table 11.5-1*, based on the building occupancy category.	I = 1.25	I = 1.25
7. Determine the seismic design category using *ASCE 7-05, Table 11.6-1*, using the S_{DS} value, and *ASCE 7-05, Table 11.6-2*, using the S_{D1} value. a. Note that whichever category is the more severe is the one selected.	Design Category B	Design Category B
8. Determine the response modification coefficient, R, system overstrength factor, Ω_0, and deflection amplification factor, C_d. This is done by first determining what type of seismic force-resisting systems the building will use. Then the coefficients can be looked up in *ASCE 7-05, Table 12.2-1*. a. This project used steel braced frames not specifically detailed for seismic resistance. b. Note that based on the seismic design category some seismic force-resisting systems are not allowed for buildings over a certain height. This limit can be checked in *ASCE 7-05, Table 12.2-1*.	R = 3 Ω_0 = 3 C_d = 3	R = 3 Ω_0 = 3 C_d = 3
9. Determine the seismic weight, W_i, for each floor of the building where i represents the floor number. Per *ASCE 7-05 Section 12.7.2*, the seismic weight will include the total dead load and 20 percent of the design snow load.	W_2 = 350 kips W_{roof} = 125 kips	W_2 = 373 kips W_3 = 456 kips W_{roof} = 170 kips
10. Sum all the W_i to get the seismic weight of the entire building, W	W = 475 kips	W = 999 kips
11. Determine the seismic response coefficient, C_S a. This coefficient is calculated using: $C_S = \frac{S_{DS}}{(\frac{R}{I})}$ b. C_S cannot be less than C_S = 0.01	C_s = 0.107	C_s = 0.107
12. Determine the C_t and x coefficients a. These coefficients are determined based on the seismic force-resisting system of the building using *ASCE 7-05, Table 12.8-2*.	C_t = 0.02 x = 0.75	C_t = 0.02 x = 0.75
13. Calculate the approximate fundamental period using the equation $T_a = C_t h_n^x$	T_a = 0.312 s	T_a = 0.312 s

a. Where h_n is the height, in feet, above the base to the highest level of the building.		
14. Calculate the total design shear at the base of the structure, V, using the equation $V = C_S W$	V = 50.67 kips	V = 106.56 kips
15. Calculate the vertical distribution factor C_{vx} for each floor using the equation: $$C_{vx} = \frac{w_x h_x^k}{\sum_{i=1}^{n} w_i h_i^k}$$ a. Where k = 1 for buildings where $T_a \leq 0.5$ sec or k = 2 for $T_a \geq 2.5$ sec. If T_a is between these ranges the k value can be conservatively taken as 2.	• 2nd Floor: C_{vx} = 0.417 • Roof: C_{vx} = 0.583	• 2nd Floor: C_{vx} = 0.284 • 3rd Floor: C_{vx} = 0.508 • Roof: C_{vx} = 0.208
16. Calculate the lateral seismic force, F_x, at each level using the equation $F_x = C_{vx} V$	• 2nd Floor: F_x = 29.56 k • Roof: F_x = 21.11 k	• 2nd Floor: F_x = 30.28 k • 3rd Floor: F_x = 54.14 k • Roof: F_x = 22.14 k
17. Apply these story shears at the center of mass of the building. Also, apply the forces at 5% eccentricity from the center of mass of the building to account for accidental Torsion. Use the most critical case as the design case (American Society of Civil Engineers, 2006).		

Appendix D: Excel Spreadsheets

Typical Beam and Girder Design Spreadsheet

Unshored Girder Sizing

Building:	Administration		- Input Cell
Floor:	1		- Output Cell
Girder Location:	On Gridline E Between Gridlines 3 & 4		

Girder Properties

Span =	18	ft
Tributary Width =	20	ft
Tributary Area =	360.00	ft^2
F_y =	50	ksi
Φ =	0.9	
E =	29000	ksi

Construction Loads

Dead Loads

Self Weight =	26	PLF
Beam Weights =	4	PSF
Beam Weights*Width =	80	PLF
Steel Deck =	2.14	PSF
Steel Deck*Width =	42.8	PLF
Total =	**148.8**	PLF

$$\text{Approximation of Beam Weight} = \frac{\frac{lb}{ft}}{\text{Beam Spacing}}$$

Live Loads

Concrete Slab =	60.86	PSF
Concrete Slab*Width =	1217.2	PLF
Ponding Effect =	121.72	PLF
Construction =	25	PSF
Construction*Width =	500	PLF
Total =	**1838.92**	PLF

w_u = 1.2D*1.6L =	3120.832	PLF

M_u =	126.394	k-ft					
$Z_x \geq$	33.705	in^3					
Deflection Limit=	0.6	in	*Due to unfactored self weight and wet concrete (AISC Design Guide 3)*				
$I_x \geq$	201.950	in^4					
Select Beam from Table 3-2							
Beam Size:	W	12	X	26			
Z_x =	37.2	in^3	OK				
I_x =	204	in^4	OK				
Calculated Deflection =	0.594	in	OK				
Service Loads							
Dead Loads							
Self Weight =	26	PLF					
Beam Weights*Width =	4	PLF					
Steel Deck*Width =	2.14	PLF					
Concrete Slab*Width =	60.86	PLF					
Ponding Effect =	6.086	PLF					
MEP =	10	PSF					
MEP*Width =	180	PLF					
Exterior Envelope =	0	PLF					
Total =	**279.09**	PLF					
Live Loads							
Floor Live Load =	100	PSF					
Floor Live Load*Width =	1800	PLF					
Total =	**1800**	PLF					
w_u = 1.2D*1.6L =	3214.90	PLF					

M_u =	130.20	k-ft	

Composite Action

f'_c =	3	ksi	
Girder Spacing =	20	ft	
b_e =	54	in	Do separate for both sides and add. Smaller of beam span/8, .5*space between adjacent beam, distance to edge of slab
Y_{con} =	6.5	in	
ΣQ_n =	95.6	k	From AISC Table 3-19
Y_1 =	1.94	in	From AISC Table 3-19
a_{req} =	0.694	in	
Y_2 =	6.15	in	

From AISC Table 3-19

Y_2 (in)	6	6.5	
Φm_n (k-ft)	211	215	
Φm_n =	212.22	k-ft	OK

From AISC Table 3-20

Y_2 (in)	6	6.5	
I_{LB} (in^4)	428	447	
I_{LB} =	433.81	in^4	

Deflection Check

0.5LL + DL Limit =	0.9	in	
0.5LL Limit =	0.6	in	
0.5LL + DL Calculated =	0.221	in	OK
0.5LL Calculated=	0.169	in	OK

Shear Studs

ΣQ_n =	95.6	k
R_p =	0.6	

R_g =	1			
Q_n =	21	k	From AISC Table 3-21	
Required # of studs for full span=	9.10		Required # of studs for full span=	$2 * \frac{\Sigma Q_n}{Q_n}$
# of Studs Selected =	10		OK	
Minimum Spacing =	4.5	in		
Maximum Spacing =	36	in		
Max Studs in one row =	17		OK	
Stud Spacing =	19.64	in	OK	

Shear Check

V_u =	28.93	k		
ΦV_n =	86	k	OK	From AISC Table 3-2

Summary

Beam Size:	W	12	X	26
# of 3/4" Shear Studs =	10			
Reactions =	28.93	k		

Typical Vibration Guidelines Spreadsheet

Gym Vibration Check

Beam

Beam:	W	18	X	76
	Span =	25	ft	
	Tributary Width =	8.3333	ft	

	Dead Load =	50	psf	(includes slab)	
	Live Load =	2.5	psf		
	E_s =	29000000	psi		
	f'_c =	3	ksi		
	E_c =	1998.25	ksi		
	A_s =	22.30	in^2		
	d =	18.20	in		
	I =	1330.00	in^4		
	b_e =	100.00	in		
	n =	10.75			
	b_e/n =	9.30	in		
	Y_{top} (in)	A (in^2)	$A*Y_{top}$	I_o (in^4)	$A(Y_{top}-Y_{bar})^2$
Concrete	1.625	30.23	49.13	26.61	1026.25
Concrete in Deck	N/A	N/A	N/A	N/A	N/A
Steel	15.35	22.30	342.31	1330.00	1391.28
	Total =	52.53	391.43	1356.61	2417.53
	Y_{bar} =	7.451	in		
	I_g =	3774.144	in^4		
	W_b =	513.50	plf		
	Deflection =	0.041	in		
	Beam Frequency =	17.42	Hz		
Top Girder					
Girder:	W	24	X	76	
	Span =	25	ft		
	Tributary Width =	25	ft		
	Dead Load =	50	psf	(includes slab)	
	Live Load =	2.5	psf		
	E_s =	29000000	psi		
	f'_c =	3	ksi		
	E_c =	1998.25	ksi		

	A_s =	22.40	in^2		
	d =	23.90	in		
	I =	2100.00	in^4		
	b_e =	120.00	in		
	n =	10.75			
	b_e/n =	11.16	in		
	Y_{top} (in)	A (in^2)	$A*Y_{top}$	I_o (in^4)	$A(Y_{top}-Y_{bar})^2$
Concrete	1.625	36.28	58.95	31.93	1077.53
Concrete in Deck	4.00	16.74	66.98	3.14	158.32
Steel	18.20	22.40	407.68	2100.00	2772.39
	Total =	75.42	533.61	2135.07	4008.24
	Y_{bar} =	7.075	in		
	I_g =	6143.311	in^4		
	W_g =	1616.50	plf		
	Deflection =	0.080	in		
	Top Girder Frequency =	12.52	Hz		

Bottom Girder

Girder:	W	21	X	55	
	Span =	25	ft		
	Tributary Width =	12.5	ft		
	Dead Load =	50	psf	(includes slab)	
	Live Load =	2.5	psf		
	E_s =	29000000	psi		
	f'_c =	3	ksi		
	E_c =	1998.25	ksi		
	A_s =	16.20	in^2		
	d =	20.80	in		
	I =	1140.00	in^4		
	b_e =	60	in	Exterior Girder	

	n =	10.75			
	b_e/n =	5.58	in		
	Y_{top} (in)	A (in^2)	A*Y_{top}	I_o (in^4)	A(Y_{top}-Y_{bar})^2
Concrete	1.625	18.14	29.48	15.97	689.29
Concrete in Deck	4.00	8.37	33.49	1.57	120.22
Steel	16.65	16.20	269.73	1140.00	1271.87
	Total =	42.71	332.69	1157.54	2081.37
	Y_{bar} =	7.789	in		
	I_g =	3238.909	in^4		
	W_g =	825.25	plf		
	Deflection =	0.077	in		
	Bottom Girder Frequency =	12.73	Hz		

Bay

f_n =	10.17	Hz		
W_t =	64.24	psf		
a_o/g =	2	%		

From Table 5.2:

Harmonic	Forcing Frequency (Hz)	Dynamic Coefficient	Damping
First	2.75	1.5	0.06
Second	5.5	0.6	0.06
Third	8.25	0.1	0.06

First Check

First Harmonic

$(f_n)_{req'd}$ =	7.19	<	10.17	OK

Second Harmonic

$(f_n)_{req'd}$ =	10.04	<	10.17	OK	
Third Harmonic					
$(f_n)_{req'd}$ =	9.72	<	10.17	OK	
Second Check					
First Harmonic					
a_1/g =	0.60				
Second Harmonic					
a_2/g =	1.25				
Third Harmonic					
a_3/g =	0.94				
Considering all 3 Harmonics					
a_m =	1.97	% of Gravity		OK	
Acceptable Bay Configuration					

Typical Spread Footing Design Spreadsheet

Spread Footing Design						
Building:	Student					- Input Cell
Location:	B-11					- Output Cell
Pier:	Yes					
Unfactored Dead Load =	117	k	Includes pier weight			
Unfactored Live Load =	96	k				
Pier Properties						
Length =	3	ft				
Base =	2	ft				
Width =	2	ft				
f'_c =	4	ksi				
f_y =	60	ksi				
Unit Weight =	145	pcf				

Soil Properties

q_a =	6000	psf	
Unit Weight =	126	pcf	

Footing Properties

Depth (T.O.F.)=	3	ft	
f'_c =	4	ksi	
f_y =	60	ksi	
Thickness =	1.5	ft	
q_e =	5404.5	psf	Based on trial thickness below
A_{req} =	39.412	ft^2	
b =	7	ft	
A =	49	ft^2	OK
q_u =	6.00	ksf	
d =	14	in	Based on trial thickness above
b_o =	152	in	
V_{u1} =	233.83	k	
V_c =	538.35	k	
Φ =	0.75		
ΦV_c =	403.76	k	OK
V_{u2} =	56.00	k	
V_c =	148.75	k	
ΦV_c =	111.57	k	OK

M_U =	1575	in-k					
a =	3	in					
A_s =	2.333	in^2					
a =	1.72	in					
A_s =	2.22	in^2					
a =	1.63	in					
A_s =	2.21	in^2					
$A_{s,min}$ =	3.92	in^2					
$A_{s,req}$ =	3.92	in^2					
Bars Selected =		7	#	7			
A_s =	4.21	in^2	OK				
Summary							
7	X	7	X	1.5	Thick	Footing	
	With						
7	#	7	In both directions				

Appendix E: Structural Cost Estimate

Table 19: Structural column cost estimate, based on national average

Column Size	Total Weight (lb.)	Cost/lb.	Cost
HSS6X6X5/16	4977	2.04	$10,153.60
HSS8X8X5/16	32532	1.7	$55,304.16
HSS10X10X5/16	6416	1.7	$10,906.61
HSS10X10X3/8	1904	1.7	$ 3,236.84
		Total =	$79,601.20

Table 20: Structural framing cost estimate, based on national average

Steel Section	Total Length (ft.)	Cost/ft.	Cost
HSS3X3X1/4	160.50	2.04	$ 327.42
HSS3-1/2X3-1/2X1/4	365.13	2.04	$ 744.87
HSS4X4X1/4	217.88	2.04	$ 444.48
HSS4X4X3/8	69.22	2.04	$ 141.20
HSS5X5X1/4	154.33	2.04	$ 314.84
HSS5X5X5/16	128.12	2.04	$ 261.36
W10X12	580.28	30	$ 17,408.28
W10X19	150.00	45	$ 6,750.00
W12X14	358.00	33	$ 11,814.00
W12X16	356.53	33	$ 11,765.34
W12X19	593.53	40	$ 23,741.24
W12X22	359.55	43	$ 15,460.74
W12X26	227.42	49	$ 11,143.42
W14X22	1267.52	46	$ 58,305.96
W14X26	146.21	48	$ 7,018.23
W14X30	152.67	55.5	$ 8,473.00
W16X26	95.33	48	$ 4,576.00
W16X31	331.39	57	$ 18,889.19
W16X40	91.67	72	$ 6,600.00
W18X35	388.69	65.5	$ 25,459.46
W18X40	116.33	73.5	$ 8,550.50
W18X76	267.67	132	$ 35,332.00
W21X68	166.42	118	$ 19,637.78
W24X76	105.00	130	$ 13,650.00
W24X94	32.67	159	$ 5,194.00
		Total =	$312,003.31

Table 21: Shear stud cost estimate, based on national average

	Total Count	Cost/Stud	Total Cost
Shear Studs	1912	2.96	$ 5,659.52

Table 22: Reinforced concrete foundation cost estimate, based on national average

Component	Total	Unit	Cost/Unit	Cost
Concrete Piers (Reinforcing)	7.95	C.Y.	1825	$ 14,504.69
Retaining Wall and Footing (Reinforcing)	235.66	C.Y.	385	$ 90,727.96
Frost Wall (Reinforcing)	60.44	C.Y.	345	$ 20,851.54
Wall Footings (Reinforcing)	25.17	C.Y.	315	$ 7,928.90
Under 5 C.Y. Spread Footings (Reinforcing)	75.25	C.Y.	405	$ 30,474.30
Over 5 C.Y. Spread Footings (Reinforcing)	18.00	C.Y.	310	$ 5,580.00
Slab on Grade (No Reinforcing)	9835.51	ft^2	3.17	$ 31,178.57
Normal Weight Elevated Slab (No Reinforcing)	6963.51	ft^2	3.24	$ 22,561.77
Lightweight Elevated Slab (No Reinforcing)	9375.09	ft^2	3.5	$ 32,812.82

Table 23: Metal floor and roof deck cost estimate, based on national average

	Total Area (ft^2)	Cost/ft^2	Total Cost
3" Deep 20 Gauge Composite Deck:	16338.60	3.62	$ 59,145.73
3" Deep 20 Gauge Roof Deck:	9709.99	2.86	$ 27,770.57

Table 24: Concrete slab reinforcing cost estimate, based on national average

	Total Area (ft^2)	Cost/100 ft^2	Total Cost
6X6-W2.9XW2.9	26174.11	70	$ 18,321.88

Table 25: Worcester location factors for structural cost estimate

Worcester Location Factor	
Concrete	118
Metals	108.4

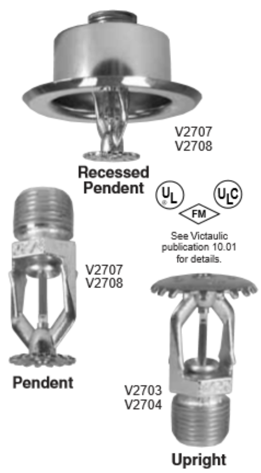
Appendix F: Sprinkler Cut Sheets

AUTOMATIC SPRINKLERS FIRE PROTECTION PRODUCTS **40.10**

V27, K5.6

Models V2703, V2704, V2707 and V2708
Standard Spray
Upright, Pendent and Recessed Pendent
Standard and Quick Response

PRODUCT DESCRIPTION



These Model V27 standard spray sprinklers are designed to produce a hemispherical spray pattern for standard commercial applications. They are available with either standard or quick response bulbs. The design incorporates state-of-the-art, heat responsive, frangible glass bulb design (standard or quick response) for prompt, precise operation.

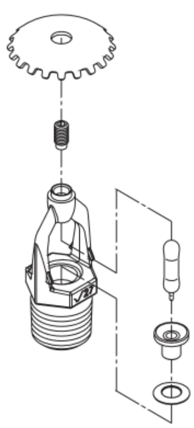
The die cast frame is more streamlined and attractive than traditional sand cast frames. It is cast with a hex-shaped wrench boss to allow easy tightening from many angles, reducing assembly effort. This sprinkler is available in various temperature ratings (see chart on page 2) and finishes to meet many design requirements.

The recessed pendent should be utilized with a Model V27 recessed escutcheon which provides up to ¾" (19 mm) of adjustments.

Sprinkler Operation
The operating mechanism is a frangible glass bulb which contains a heat responsive liquid. During a fire, the ambient temperature rises causing the liquid in the bulb to expand. When the ambient temperature reaches the rated temperature of the sprinkler, the bulb shatters. As a result, the waterway is cleared of all sealing parts and water is discharged towards the deflector. The deflector is designed to distribute the water in a pattern that is most effective in controlling the fire.

Coverage
For coverage area and sprinkler placement, refer to NFPA 13 standards.

TECHNICAL SPECIFICATIONS



Models: V2703, V2704, V2707, V2708

Style: Pendent, Upright or Recessed Pendent

Nominal Orifice Size: ½" (13 mm)

K-Factor: 5.6 Imp. (8,1 S.I.^)

Nominal Thread Size: ½" NPT (15 mm)

Max. Working Pressure: 175 psi (1200 kPa) FM Global; 250 psi (1725 kPa) UL

Factory Hydrostatic Test: 100% @ 500 psi (3450 kPa)

Min. Operating Pressure: 7 psi (48 kPa)

Temperature Rating: See chart on page 2.

MATERIAL SPECIFICATIONS

Upright Deflector: Bronze per UNS C22000

Pendent Deflector: Bronze per UNS C51000

Bulb: Glass with glycerin solution.
Bulb Nominal Diameter:
- ❑ Standard: 5,0 mm
- ❑ Quick Response: 3,0 mm

Load Screw: Bronze per UNS C65100

Pip Cap: Bronze per UNS C65100

Spring: Beryllium nickel

Seal: Teflon* tape

Frame: Die cast brass 65-30

Lodgement Spring: Stainless steel per UNS S30200

ACCESSORIES

Installation Wrench:
- ❑ Open End: V27
- ❑ Recessed: V38, V38-3
- ❑ Socket: V27

Finishes:
- ❑ Plain brass
- ❑ Chrome plated
- ❑ White painted**
- ❑ Custom painted**
- ❑ Lead**
- ❑ Proprietary nickel Teflon* coating**

155, 200, 286 Standard Response Only:
- ❑ Wax**
- ❑ Wax over lead**

For cabinets and other accessories refer to separate sheet.

NOTE: Weather resistant recessed escutcheons available upon request.

^ For K-Factor when pressure is measured in Bar, multiply S.I. units by 10.0.

* Teflon is a registered trademark of Dupont Co.

**UL Listed for corrosion resistance in all configurations.

VICTAULIC® IS AN ISO 9001 CERTIFIED COMPANY

Victaulic Company of America	Victaulic Company of Canada	Victaulic Europe	Victaulic America Latina	Victaulic Asia Pacific
Phone: 1-800-PICK-VIC (1-800-742-5842)	Phone: 905-884-7444	Phone: 32-9-381-1500	Phone: 610-559-3300	Phone: 86-21-58855151
Fax: 610-250-8817	Fax: 905-884-9774	Fax: 32-9-380-4438	Fax: 610-559-3608	Fax: 86-21-58851298
e-mail:pickvic@victaulic.com	e-mail: viccanada@victaulic.com	e-mail: viceuro@victaulic.be	e-mail: vical@victaulic.com	e-mail: vicap@victaulic.com

APPROVALS/LISTINGS

Model	Orifice Size Inches millimeters	Nominal K-Factor Imperial S.I.^	Response	Deflector Type	Approved Temperature Ratings °F/°C ‡ Ω				
					UL	FM	ULC	NYC/MEA†	CSFM §
V2703	½ 13	5.6 8,1	Standard	Upright	135 - 360 57 - 182	135 - 360 57 - 182	135 - 360 57 - 182	135 - 360 57 - 182	135 - 360 57 - 182
V2707	½ 13	5.6 8,1	Standard	Pendent	135 - 360 57 - 182	135 - 360 57 - 182	135 - 360 57 - 182	135 - 360 57 - 182	135 - 360 57 - 182
V2707	½ 13	5.6 8,1	Standard	Recessed Pendent Up to ¾" Adjustment	135 - 286 57 - 141	135 - 200 57 - 93	135 - 286 57 - 141	135 - 286 57 - 141	135 - 286 57 - 141
V2704	½ 13	5.6 8,1	Quick	Upright	135 - 286 57 - 141	135 - 286 57 - 141	135 - 286 57 - 141	135 - 286 57 - 141	135 - 286 57 - 141
V2708	½ 13	5.6 8,1	Quick	Pendent	135 - 286 57 - 141	135 - 286 57 - 141	135 - 286 57 - 141	135 - 286 57 - 141	135 - 286 57 - 141
V2708	½ 13	5.6 8,1	Quick	Recessed Pendent Up to ½" Adjustment	135 - 200 57 - 93	135 - 200 57 - 93	135 - 200 57 - 93	135 - 200 57 - 93	135 - 200 57 - 93
V2708	½ 13	5.6 8,1	Quick	Recessed Pendent Up to ¾" Adjustment	135 - 200 57 - 93	No	135 - 200 57 - 93	135 - 200 57 - 93	135 - 200 57 - 93

‡ Listings and approval as of printing. Ω All are approved open, except for areas designated "No".
^ For K-Factor when pressure is measured in Bar, multiply S.I. units by 10.
† MEA #62-99-E. § CSFM #7690-0531:112

RATINGS

All glass bulbs are rated for temperatures from -67°F (-55°C) up to those shown in adjacent table.

Sprinkler Temperature Classification	Victaulic Part Identification	Temperature – °F/°C		Glass Bulb Color
		Nominal Temperature Rating	Maximum Ambient Temp. Allowed	
Ordinary	A	135 57	100 38	Orange
Ordinary	C	155 68	100 38	Red
Intermediate	E	175 79	150 65	Yellow
Intermediate	F	200 93	150 65	Green
High	J	286 141	225 ~ 107	Blue
Extra High ‡	K	360 182	300 149	Purple
– ‡	M	Open	– –	No Bulb

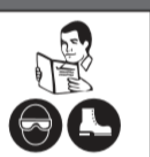
‡ Standard response only.
All are approved open, except for areas designated "No".
~ 150/65 if wax coated.

ORDERING INFORMATION

Please specify the following when ordering:

- ❑ Sprinkler Model Number
- ❑ Style
- ❑ Temperature Rating
- ❑ K-Factor
- ❑ Thread Size
- ❑ Quantity
- ❑ Sprinkler Finish
- ❑ Escutcheon Finish
- ❑ Wrench Model Number

⚠ WARNING



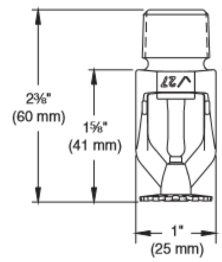
- **Always read and understand installation, care, and maintenance instructions, supplied with each box of sprinklers, before proceeding with installation of any sprinklers.**
- **Always wear safety glasses and foot protection.**
- **Depressurize and drain the piping system before attempting to install, remove, or adjust any Victaulic piping products.**
- **Installation rules, especially those governing obstruction, must be strictly followed.**
- **Painting, plating, or any re-coating of sprinklers (other than that supplied by Victaulic) is not allowed.**

Failure to follow these instructions could result in serious personal injury and/or property damage.

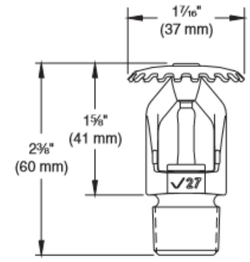
The owner is responsible for maintaining the fire protection system and devices in proper operating condition. For minimum maintenance and inspection requirements, refer to the current National Fire Protection Association pamphlet that describes care and maintenance of sprinkler systems. In addition, the authority having jurisdiction may have additional maintenance, testing, and inspection requirements that must be followed.

If you need additional copies of this publication, or if you have any questions about the safe installation of this product, contact Victaulic World Headquarters, P.O. Box 31, Easton, Pennsylvania 18044-0031, 610-559-3300.

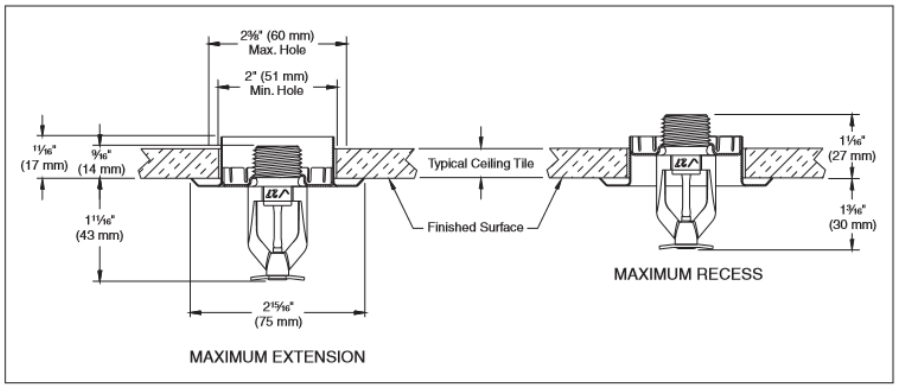
DIMENSIONS



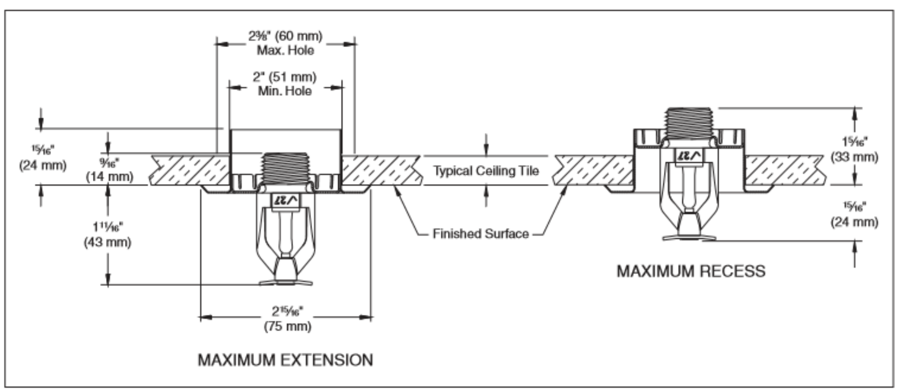
Standard Pendent - V2707, V2708



Standard Upright - V2703, V2704



½" Adjustment
Recessed - V2707, V2708
(Drawing not to scale)



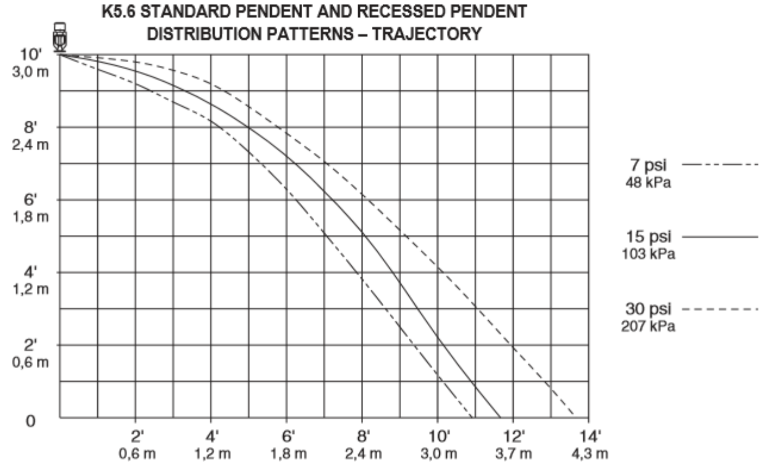
¾" Adjustment
Recessed - V2707, V2708
(Drawing not to scale)

AVAILABLE WRENCHES

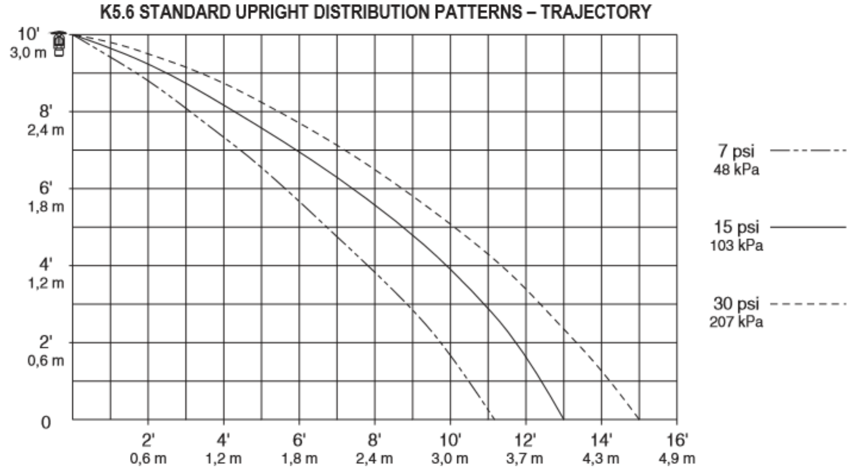
	V27 Socket	V38 or V38-3 Recessed	V27 Open End
V2707, V2708 Pendent	✓	✓	✓
V2707, V2708 Recessed Pendent	✓	✓	–
V2703, V2704 Upright	–	✓	✓

DISTRIBUTION PATTERNS

MODELS V2707, V2708
K5.6 STANDARD PENDENT AND RECESSED PENDENT
DISTRIBUTION PATTERNS – TRAJECTORY



MODELS V2703, V2704
K5.6 STANDARD UPRIGHT DISTRIBUTION PATTERNS – TRAJECTORY



NOTES:

1. Data shown is approximate and can vary due to differences in installation.

2. These graphs illustrate approximate trajectories, floor-wetting, and wall-wetting patterns for these specific Victaulic FireLock Automatic Sprinklers. They are provided as information for guidance in avoiding obstructions to sprinklers and should not be used as minimum sprinkler spacing rules for installation. Refer to the appropriate NFPA National Fire Code and the authority having jurisdiction for specific information regarding obstructions, spacing limitations and area of coverage requirements. Failure to follow these guidelines could adversely affect the performance of the sprinkler and will void all Listings, Approvals and Warranties.

3. All patterns are symmetrical to the centerline of the waterway.

WARRANTY

Refer to the Warranty section of the current Price List or contact Victaulic for details.

V34, K11.2

SEE VICTAULIC PUBLICATION 10.01 FOR DETAILS

Standard Spray Pendent and Upright, Standard and Quick Response, Storage Protection (density/area) Sprinklers Standard Response

V3403, V3404, V3407, V3408 STANDARD RESPONSE

PENDENT
(V3407 AND V3408)

UPRIGHT
(V3403 AND V3404)

The Models V3403, V3404, V3407 and V3408 Standard Spray Sprinklers are designed to protect any hazard defined within NPFA 13 where Standard Spray Sprinklers are allowed as fire protection. The Models V3403 and V3407 standard response sprinklers are also special sprinklers designed, tested and Listed for "Storage Protection" utilizing the density/area criteria per NFPA 13, 2002 edition (for example: Figure 12.3.3.1.5(b) Note 2, Figure 12.3.3.1.5(d) Note 5, Paragraphs 12.3.3.5.1.2, 12.3.2.5.1.2, etc.) In addition the FM Global Approval Guide and Loss Prevention Data Sheets must also be followed when installing these Model V34 sprinklers. FM Global refers to all these models as "Control Mode" sprinklers for use in storage applications utilizing the density/area design method. The discharge rates for Model V34 (ELO) sprinklers are twice that of standard ½" (15 mm) sprinklers and up to 60 percent higher than 17/32" (20 mm) orifice sprinklers. The design incorporates state-of-the-art, heat responsive, frangible glass bulb design (standard or quick response) for prompt, precise operation.

The die cast frame is more streamlined and attractive than traditional sand cast frames. It is cast with a hex-shaped wrench boss to allow easy tightening from many angles, reducing assembly effort. This sprinkler is available in various temperature ratings (see chart on page 2) to meet many design requirements.

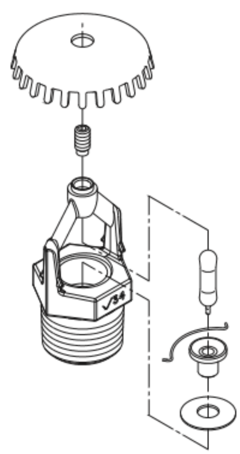
SPRINKLER OPERATION:

The operating mechanism is a frangible glass bulb which contains a heat responsive liquid. During a fire, the ambient temperature rises causing the liquid in the bulb to expand. When the ambient temperature reaches the rated temperature of the sprinkler, the bulb shatters. As a result, the waterway is cleared of all sealing parts and water is discharged towards the deflector. The deflector is designed to distribute the water in a pattern that is most effective in controlling the fire.

COVERAGE:

For coverage area and sprinkler placement, refer to NFPA 13 standards, the FM Global Approval Guide and Loss Prevention Data Sheets where applicable.

TECHNICAL SPECIFICATIONS:



(EXAGGERATED FOR CLARITY)

Models: V3403, V3404, V3407, V3408
Style: Pendent or Upright
Nominal Orifice Size: ⅝"/16 mm
K-Factor: 11.2 Imp./16.1 S.I.^
Nominal Thread Size: ¾" NPT/20 mm
Max. Working Pressure: 175 psi/1200 kPa
Factory Hydrostatic Test: 100% @ 500 psi/3450 kPa
Min. Operating Pressure: 7 psi/48 kPa UL, NFPA applications; 10 psi/69 kPa FM Global applications.
Temperature Rating: See chart on page 2.

MATERIAL SPECIFICATIONS
Upright Deflector: Brass per UNS C22000
Pendent Deflector: Brass per UNS C51000
Bulb: Glass with glycerin solution.
Bulb Nominal Diameter:
- Standard: 5.0 mm
- Quick Response: 3.0 mm

Load Screw: Brass per UNS C65100
Pip Cap: Brass per UNS C65100
Seal: Teflon* tape
Spring: Beryllium nickel
Frame: Die cast brass
Lodgement Spring:
Stainless steel per UNS S30200

ACCESSORIES
Installation Wrench:
- Open End: V34
- Recessed: V34

Sprinkler Finishes:
- Plain brass
- Chrome plated
- White painted**‡
- Lead**
- Proprietary Nickel*
- Teflon coating**

155 and 200SR Only:
- Wax**
- Wax over lead**

For cabinets and other accessories refer to separate sheet.

^ For K-Factor when pressure is measured in Bar, multiply S.I. units by 10.0.
* Teflon is a registered trademark of Dupont Co.
** UL, ULC Listed for corrosion resistance in all configurations.
‡ Not FM approved.

JOB/OWNER	CONTRACTOR	ENGINEER
System No. ________	Submitted By ________	Spec Sect ________ Para ________
Location ________	Date ________	Approved ________
		Date ________

V34, K11.2

Standard Spray Pendent and Upright, Standard and Quick Response, Storage Protection (density/area) Sprinklers Standard Response

V3403, V3404, V3407, V3408 STANDARD RESPONSE

APPROVALS/LISTINGS

Model	Orifice Size	Nominal K-Factor	Response	Deflector Type	Approved Temperature Ratings ‡ @
	Inches mm	Imperial S.I.^	Standard or Quick		
V3407	⅝ 16	11.2 16.1	Standard	Pendent	1, 2, 3, 4, 5 – B
V3403	⅝ 16	11.2 16.1	Standard	Upright	1, 2, 3, 4, 5 – B
V3408	⅝ 16	11.2 16.1	Quick	Pendent	1, 2, 3, 4, 5 – B
V3404	⅝ 16	11.2 16.1	Quick	Upright	1, 2, 3, 4, 5 – B

‡ Listings and approval as of printing.

@ All are approved open, except for areas designated "No".

^ For K-Factor when pressure is measured in Bar, multiply S.I. units by 10.0.

APPROVED TEMPERATURE RATINGS

Approval	Temperature Rating
1 – UL	A – 135°F/57°C, 155°F/68°C, 175°F/79°C, 200°F/93°C, 286°F/141°C, 360°F/182°C
2 – FM	B – 135°F/57°C, 155°F/68°C, 175°F/79°C, 200°F/93°C, 286°F/141°C
3 – ULC	C – 135°F/57°C, 155°F/68°C, 175°F/79°C, 200°F/93°C
4 – NYC/MEA †	D – No
5 – CSFM §	

† MEA #62-99-E.

§ CSFM #7690-0531:112

V34, K11.2

Standard Spray Pendent and Upright, Standard and Quick Response, Storage Protection (density/area) Sprinklers Standard Response

V3403, V3404, V3407, V3408 STANDARD RESPONSE

RATINGS

All glass bulbs are rated for temperatures from –67°F (–55°C) to those shown in the table below.

Sprinkler Temperature Classification	Victaulic Part Identification	Temperature – °F/°C		Glass Bulb Color
		Nominal Temperature Rating	Maximum Ambient Temperature Allowed	
Ordinary	A	135 57	100 38	Orange
Ordinary	C	155 68	100 38	Red
Intermediate	E	175 79	150 65	Yellow
Intermediate	F	200 93	150 65	Green
High	J	286 141	225 ~ 107	Blue
– ‡	M	Open	– –	No Bulb

‡ Standard response only.

All are approved open, except for areas designated "No".

~ 150/65 if wax coated.

ORDERING INFORMATION

Please specify the following when ordering:

Sprinkler Model Number	
Style	
Temperature Rating	
K-Factor	
Thread Size	
Sprinkler Finish	
Quantity	
Wrench Model Number	

V34, K11.2

Standard Spray Pendent and Upright, Standard and Quick Response, Storage Protection (density/area) Sprinklers Standard Response

V3403, V3404, V3407, V3408 STANDARD RESPONSE

WARNING

WARNING

- **Always read and understand installation, care, and maintenance instructions, supplied with each box of sprinklers, before proceeding with installation of any sprinklers.**
- **Always wear safety glasses and foot protection.**
- **Depressurize and drain the piping system before attempting to install, remove, or adjust any Victaulic piping products.**
- **Installation rules, especially those governing obstruction, must be strictly followed.**
- **Painting, plating, or any re-coating of sprinklers (other than that supplied by Victaulic) is not allowed.**

Failure to follow these instructions could result in serious personal injury and/or property damage.

The owner is responsible for maintaining the fire protection system and devices in proper operating condition. For minimum maintenance and inspection requirements, refer to the current National Fire Protection Association pamphlet that describes care and maintenance of sprinkler systems. In addition, the authority having jurisdiction may have additional maintenance, testing, and inspection requirements that must be followed.

If you need additional copies of this publication, or if you have any questions about the safe installation of this product, contact Victaulic World Headquarters: P.O. Box 31, Easton, Pennsylvania 18044-0031 USA, Telephone: 001-610-559-3300.

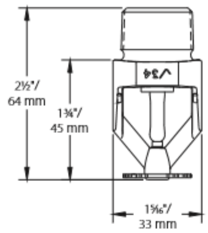
V34, K11.2

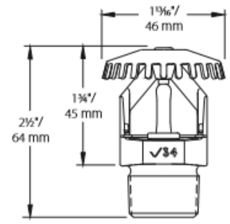
Standard Spray Pendent and Upright, Standard and Quick Response, Storage Protection (density/area) Sprinklers Standard Response

V3403, V3404, V3407, V3408 STANDARD RESPONSE

DIMENSIONS

Standard Upright – V3403, V3404





V34, K11.2

Standard Spray Pendent and Upright, Standard and Quick Response, Storage Protection (density/area) Sprinklers Standard Response

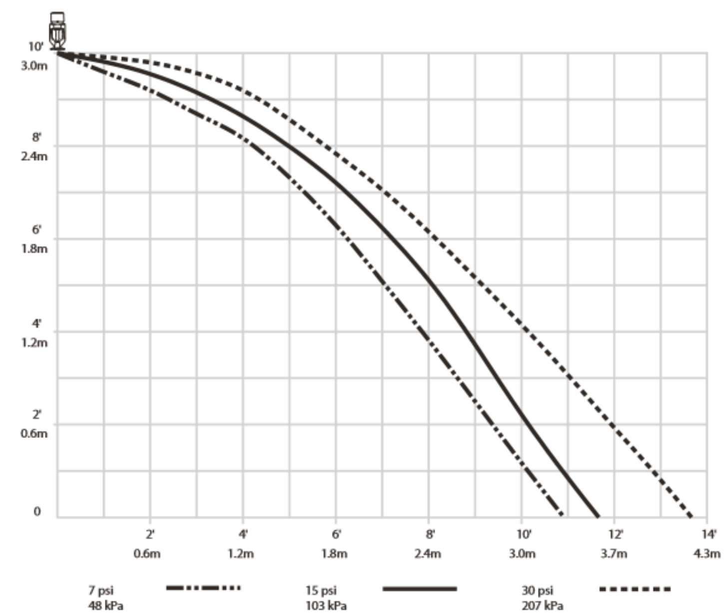
V3403, V3404, V3407, V3408 STANDARD RESPONSE

AVAILABLE WRENCHES

Sprinkler Type	V34 Recessed	V34 Open End
Pendent and Upright	yes	yes

DISTRIBUTION PATTERNS

Models V2707, V2708
K5.6 standard pendent and recessed pendent distribution patterns – trajectory



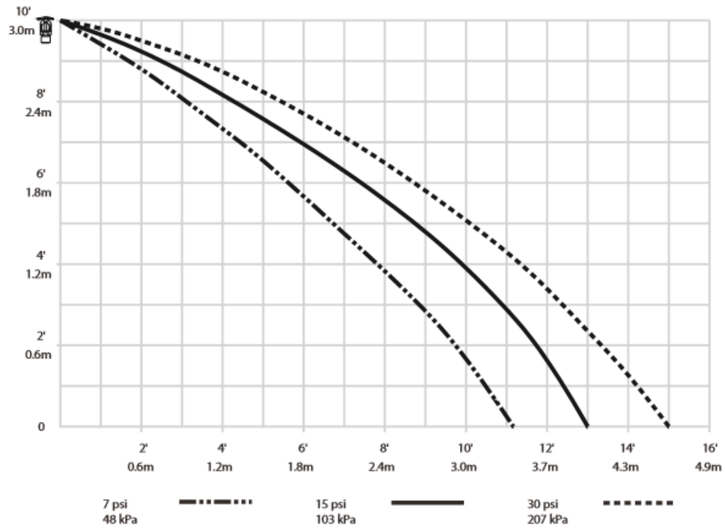
V34, K11.2

Standard Spray Pendent and Upright, Standard and Quick Response, Storage Protection (density/area) Sprinklers Standard Response

V3403, V3404, V3407, V3408 STANDARD RESPONSE

DISTRIBUTION PATTERNS

Models V2703, V2704
K5.6 standard upright distribution patterns – trajectory



NOTES:

1. Data shown is approximate and can vary due to differences in installation.
2. These graphs illustrate approximate trajectories, floor-wetting, and wall-wetting patterns for these specific Victaulic FireLock Automatic Sprinklers. They are provided as information for guidance inavoiding obstructions to sprinklers and should not be used as minimum sprinkler spacing rules for installation. Refer to the appropriate NFPA National Fire Code, FM Global Approval Guide and Loss Prevention Data Sheets or the Authority Having Jurisdiction for specific information regarding obstructions, spacing limitations and area of coverage requirements. Failure to follow these guidelines could adversely affect the performance of the sprinkler and will void all Listings, Approvals and Warranties.
3. All patterns are symmetrical to the centerline of the waterway.

V34, K11.2

Standard Spray Pendent and Upright, Standard and Quick Response, Storage Protection (density/area) Sprinklers Standard Response

V3403, V3404, V3407, V3408 STANDARD RESPONSENSE

WARRANTY	Refer to the Warranty section of the current Price List or contact Victaulic for details.
NOTE	This product shall be manufactured by Victaulic Company. All products to be installed in accordance with current Victaulic installation/assembly instructions. Victaulic reserves the right to change product specifications, designs and standard equipment without notice and without incurring obligations.

WCAS-6XGLG9

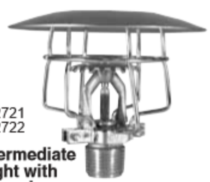
V27, K5.6

Models V2721, V2722, V2723 and V2724 Intermediate Level Standard Spray Upright and Pendent Standard and Quick Response

PRODUCT DESCRIPTION

V2723
V2724
V27 Intermediate Pendent

V2721
V2722
Upright
V27 Intermediate Upright†



V2721
V2722
V27 Intermediate Upright with Guard

These Model V27 Intermediate Level sprinklers incorporate a water shield plate to prevent water from higher level sprinklers from interfering with normal operation. These intermediate level sprinklers are designed for use in intermediate levels of rack storage or other open grate storage arrangements, where they may be exposed to upper level or ceiling level sprinklers. They are available with either standard or quick response bulbs. The design incorporates state-of-the-art, heat responsive, frangible glass bulb design (standard or quick response) for prompt, precise operation.

The die cast frame is more streamlined and attractive than traditional sand cast frames. It is cast with a hex-shaped wrench boss to allow easy tightening from many angles, reducing assembly effort. This sprinkler is available in various temperature ratings (see chart on page 2) to meet many design requirements.

Sprinkler Operation

The operating mechanism is a frangible glass bulb which contains a heat responsive liquid. During a fire, the ambient temperature rises causing the liquid in the bulb to expand. When the ambient temperature reaches the rated temperature of the sprinkler, the bulb shatters. As a result, the waterway is cleared of all sealing parts and water is discharged towards the deflector. The deflector is designed to distribute the water in a pattern that is most effective in controlling the fire.

Coverage

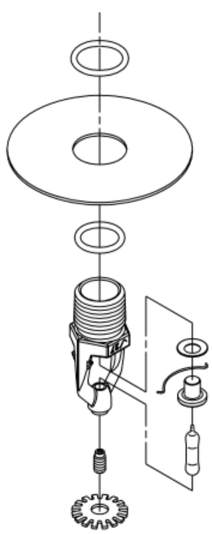
For coverage area and sprinkler placement, refer to NFPA 13 standards.

Installation

The V2721 and V2722 intermediate level upright sprinklers are field assembled from V2703 or V2704 sprinklers respectively with the V27 intermediate upright guard sold separately (see Submittal 40.83 and I-40 instruction sheet shipped with the sprinklers). They are also available factory assembled with intermediate shield only. The V2723 and V2724 intermediate level pendent sprinklers are field assembled from V2707 or V2708 sprinklers respectively with the V27 intermediate level shield kit sold separately (see Z10SHIELD0 instruction sheet shipped with the kit).

Request Victaulic publication 40.01 for details.

TECHNICAL SPECIFICATIONS



(Exaggerated for clarity)

Models: V2721, V2722, V2723, V2724

Style: Intermediate Level Pendent or Upright

Nominal Orifice Size: ½" (13 mm)

K-Factor: 5.6 Imp. (8,1 S.I.^)

Nominal Thread Size: ½" NPT (15 mm)

Max. Working Pressure: 175 psi (1200 kPa)

Factory Hydrostatic Test: 100% @ 500 psi (3450 kPa)

Min. Operating Pressure: 7 psi (48 kPa)

Temperature Rating: See chart on page 2.

MATERIAL SPECIFICATIONS

Upright Deflector: Bronze per UNS C22000

Pendent Deflector: Bronze per UNS C51000

Plate: Bronze per UNS C22000

O-rings: EPDM ‡

Bulb: Glass with glycerin solution.

Bulb Nominal Diameter:
- ❑ Standard: 5,0 mm
- ❑ Quick Response: 3,0 mm

Load Screw: Bronze per UNS C65100

Pip Cap: Bronze per UNS C65100

Spring: Beryllium nickel

Seal: Teflon* tape

Frame: Die cast brass 65-30

Lodgement Spring: Stainless steel per UNS S30200

ACCESSORIES

Installation Wrench:
- ❑ Open End: V27
- ❑ Recessed: V38
- ❑ Socket: V27

Sprinkler Finishes:
- ❑ Plain brass only

^ For K-Factor when pressure is measured in Bar, multiply S.I. units by 10.0.

*Teflon is a registered trademark of Dupont Co.

‡ O-rings are used to hold the shield in place and do not affect the orifice seal.

† Cannot be installed using V27 sprinkler guard.

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2551 Rev.E 8/05 SKU #WCAS-6F4G74 Printed in U.S.A.

APPROVALS/LISTINGS

Models	Orifice Size Inches/mm	Nominal K-Factor Imperial S.I.^	Response	Deflector Type	Approved Temperature Ratings °F/°C ‡				
					UL	FM	ULC	NYC/MEA†	CSFM
V2721	½ 13	5.6 8,1	Standard	Intermediate Upright	135 - 286 57 - 141	135 - 286 57 - 141	135 - 286 57 - 141	135 - 286 57 - 141	135 - 286 57 - 141
V2723	½ 13	5.6 8,1	Standard	Intermediate Pendent	135 - 286 57 - 141	135 - 286 57 - 141	135 - 286 57 - 141	135 - 286 57 - 141	135 - 286 57 - 141
V2722	½ 13	5.6 8,1	Quick	Intermediate Upright	135 - 286 57 - 141	135 - 286 57 - 141	135 - 286 57 - 141	135 - 286 57 - 141	135 - 286 57 - 141
V2724	½ 13	5.6 8,1	Quick	Intermediate Pendent	135 - 286 57 - 141	135 - 286 57 - 141	135 - 286 57 - 141	135 - 286 57 - 141	135 - 286 57 - 141

‡ Listings and approval as of printing. Not all temperature rating combinations are Approved or Listed. Check Victaulic for specific combinations.
^ For K-Factor when pressure is measured in Bar, multiply S.I. units by 10.
† MEA #62-99-E.

RATINGS

All glass bulbs are rated for temperatures from -65°F (-54°C) up to those shown in adjacent table.

Sprinkler Temperature Classification	Victaulic Part Identification	Temperature – °F/°C		Glass Bulb Color
		Nominal Temperature Rating	Maximum Ambient Temp. Allowed	
Ordinary	A	135 57	100 38	Orange
Ordinary	C	155 68	100 38	Red
Intermediate	E	175 79	150 65	Yellow
Intermediate	F	200 93	150 65	Green
High	J	286 141	225 107	Blue

ORDERING INFORMATION

Please specify the following when ordering:

❑ **V27 Intermediate Upright with or without Guard**
❑ Sprinkler Model Number
❑ Style
❑ Temperature Rating

❑ **V27 Intermediate Pendent Shield Kit**
❑ K-Factor
❑ Thread Size

❑ Quantity
❑ Wrench Model Number

⚠ WARNING

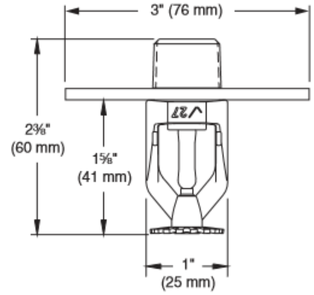
- **Always read and understand installation, care, and maintenance instructions, supplied with each box of sprinklers, before proceeding with installation of any sprinklers.**
- **Always wear safety glasses and foot protection.**
- **Depressurize and drain the piping system before attempting to install, remove, or adjust any Victaulic piping products.**
- **Installation rules, especially those governing obstruction, must be strictly followed.**
- **Painting, plating, or any re-coating of sprinklers (other than that supplied by Victaulic) is not allowed.**

Failure to follow these instructions could result in serious personal injury and/or property damage.

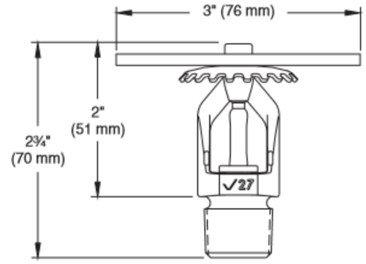
The owner is responsible for maintaining the fire protection system and devices in proper operating condition. For minimum maintenance and inspection requirements, refer to the current National Fire Protection Association pamphlet that describes care and maintenance of sprinkler systems. In addition, the authority having jurisdiction may have additional maintenance, testing, and inspection requirements that must be followed.

If you need additional copies of this publication, or if you have any questions about the safe installation of this product, contact Victaulic World Headquarters, P.O. Box 31, Easton, Pennsylvania 18044-0031, 610-559-3300.

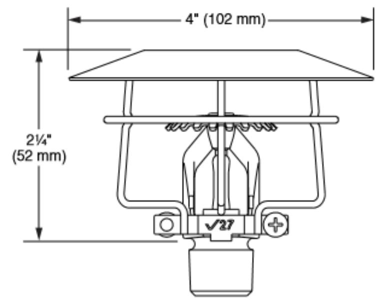
DIMENSIONS



Intermediate Pendent – V2723, V2724



Intermediate Upright – V2721, V2722



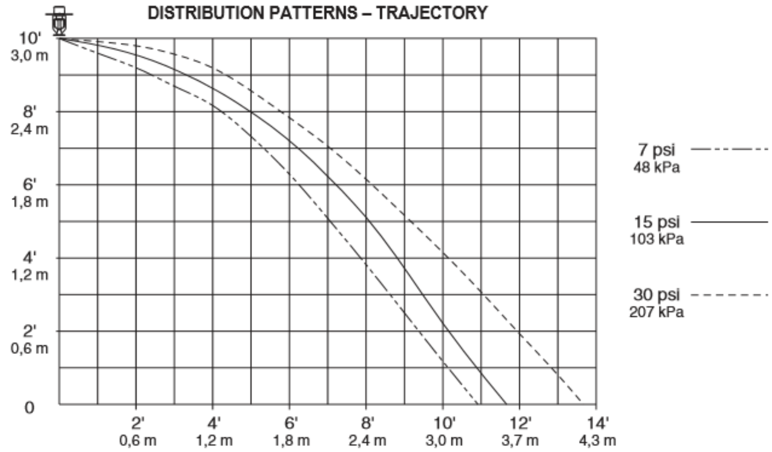
Intermediate Upright with Guard – V2721, V2722

AVAILABLE WRENCHES

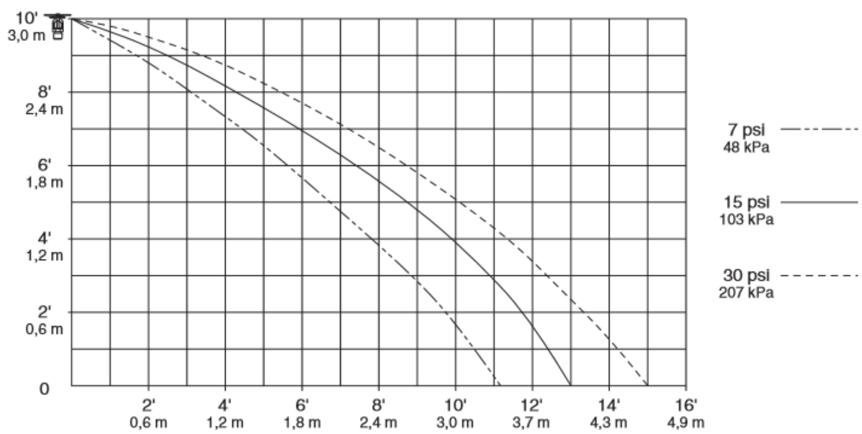
	V38-3 Recessed	V27 Open End
V2723, V2724 Intermediate Pendent	✓	✓
V2721, V2722 Intermediate Upright	–	✓

DISTRIBUTION PATTERNS

MODELS V2723, V2724
K5.6 INTERMEDIATE STANDARD PENDENT
DISTRIBUTION PATTERNS – TRAJECTORY



MODELS V2721, V2722
K5.6 INTERMEDIATE STANDARD UPRIGHT
DISTRIBUTION PATTERNS – TRAJECTORY



NOTES:

1. Data shown is approximate and can vary due to differences in installation.

2. These graphs illustrate approximate trajectories, floor-wetting, and wall-wetting patterns for these specific Victaulic FireLock Automatic Sprinklers. They are provided as information for guidance in avoiding obstructions to sprinklers and should not be used as minimum sprinkler spacing rules for installation. Refer to the appropriate NFPA National Fire Code or the Authority Having Jurisdiction for specific information regarding obstructions, spacing limitations and area of coverage requirements. Failure to follow these guidelines could adversely affect the performance of the sprinkler and will void all Listings, Approvals and Warranties.

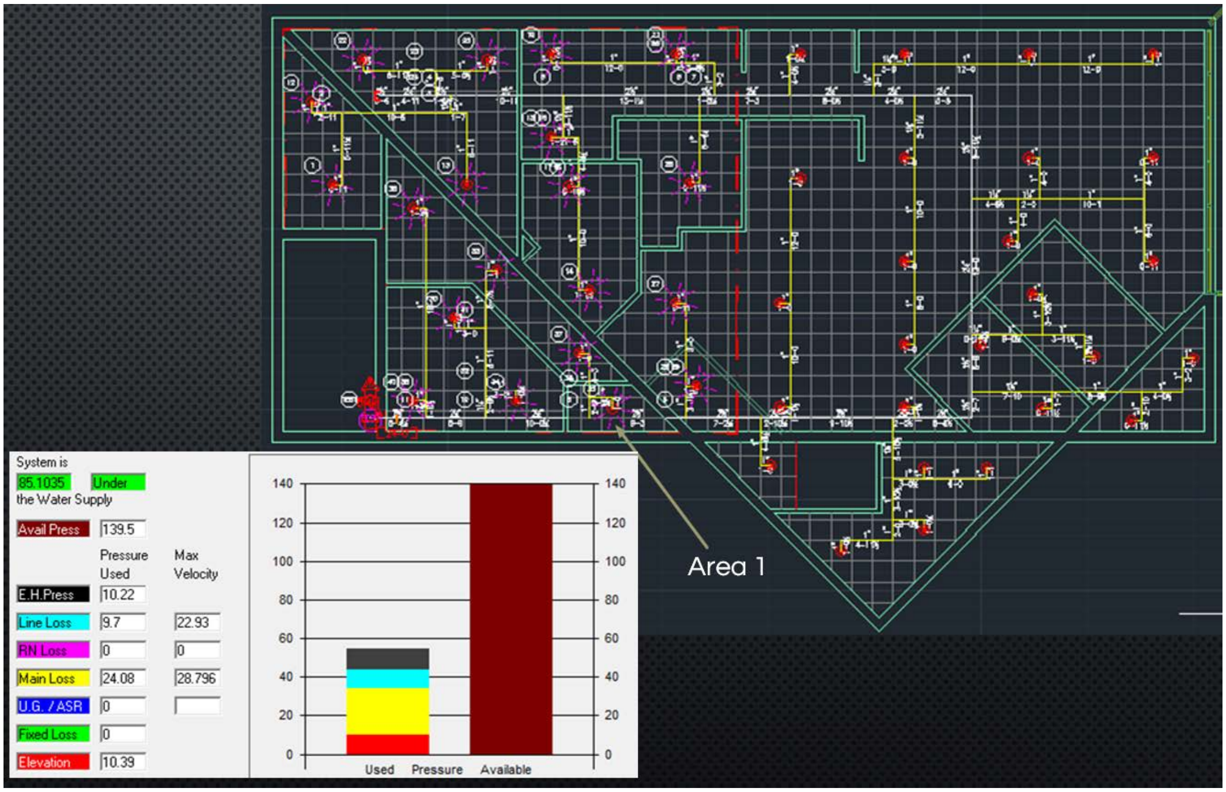
3. All patterns are symmetrical to the centerline of the waterway.

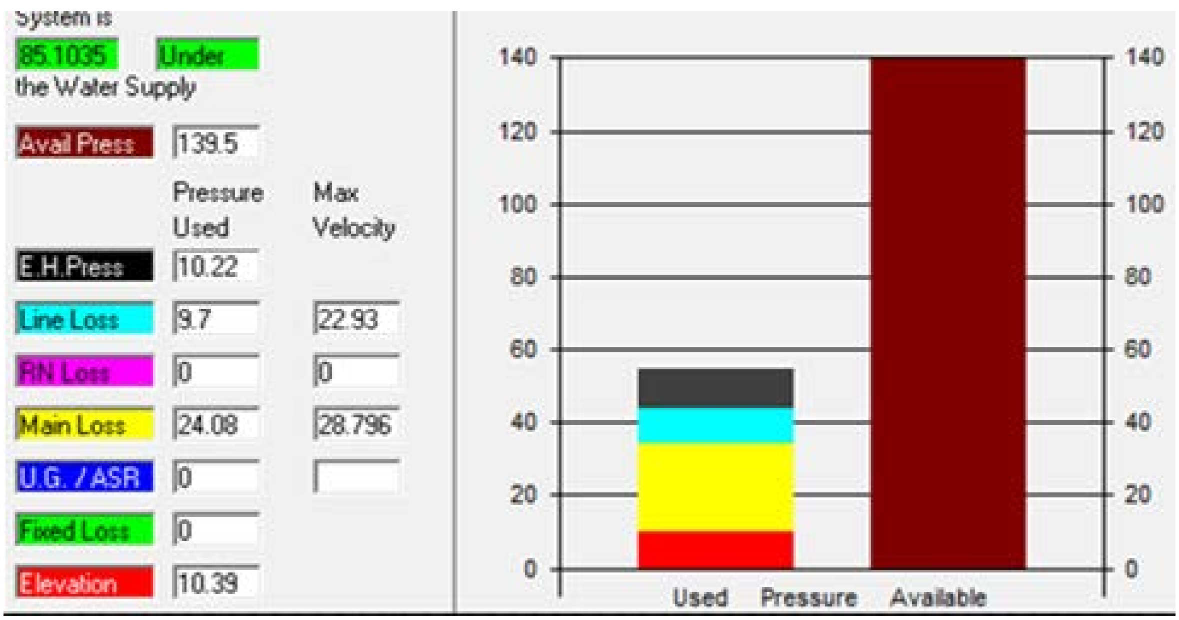
WARRANTY

Refer to the Warranty section of the current Price List or contact Victaulic for details.

Appendix G: Sprinkler System Hydraulic Calculations

Administration Building





Appendix H: Rooftop Unit Selection

24-Mar-16					
RTU-ANAL					
	Manufacturer				
	Model	Standard Efficiency 60 Hz	High Efficency 60 hz	Standard Efficiency 50 Hz	High Efficiency 60 Hz
	Nominal Size	40 Ton	40 Ton	41.7 Ton	50 Ton
		Draw-Thru	Blow-Thru	Draw-Thru	Draw-Thru
	Psych Chart Point			@15500 CFM	
Air Ent'g Condenser		90	90	90	90
Outdoor Air DB	A	85	85	85	85
Outdoor Air WB		74	74	74	74
Outdoor Air lb/lb		0.0155	0.0155	0.0155	0.0155
Supply CFM		14025	14025	14025	14025
Outdoor Air CFM		2590	2590	2590	2590
Indoor Air DB	B	76.0	76.0	76.0	76.0
Indoor Air RH		50%	50%	50%	50%
Indoor Air WB		63.3	63.3	63.3	63.3
Indoor Air lb/lb		0.0096	0.0096	0.0096	0.0096
Plenum Rise		0.0	0.0	0.0	0.0
Plenum Air DB	C	76.0	76.0	76.0	76.0
Plenum Air lb/lb		0.0096	0.0096	0.0096	0.0096
Return Fan Type		NONE	NONE	NONE	NONE
Return Fan CFM		0	-	0	0
Return Fan SP					
Return Fan Eff'y					
Return Fan BHP					
Return Fan BTUH *					
Return Fan Rise					
RF Lvg Air DB	D	76.0	76.0	76.0	76.0
RF Lvg Air lb/lb		0.0096	0.0096	0.0096	0.0096

Mixed Air DB	E	77.7	77.7	77.7	77.7
Mixed Air lb/lb		0.0107	0.0107	0.0107	0.0107
BT Fan Type		NONE	NONE	NONE	NONE
BT Supply Fan SP					
BT Supply Fan Eff'y					
BT Supply Fan BHP					
BT Supply Fan BTUH *					
BT Supply Fan Rise					
Entering Air DB	F	77.7	77.7	77.7	77.7
Entering Air lb/lb		0.0107	0.0107	0.0107	0.0107
Entering Air "h"		30.35	30.35	30.35	30.35
Ln (h)		3.413	3.413	3.413	3.413
Entering Air WB		65.4	65.4	65.4	65.4
Unit MBH Total		555.0	567.0	575.0	656.0
Unit MBH Sensible		428.0	445.0	451.0	481.0
Unit MBH Latent		127.0	122.0	124.0	175.0
Coil Leaving Air DB	G	49.9	48.8	48.4	46.5
Coil Leaving Air "h"		21.56	21.37	21.24	19.96
Ln (h)		3.071	3.062	3.056	2.994
Coil Leaving Air lb/lb		0.0088	0.0089	0.0089	0.0081
Coil Leaving Air WB		52.3	51.9	51.7	49.4
DT Fan Type		2@22.5FC/IGV	2@22.5FC/IGV	2@22FC/IGV	2@22FC/IGV
DT Supply Fan SP		1.98	1.1	1.06	1.06
DT Supply Fan Eff'y		63%	63%	63%	63%
DT Supply Fan BHP		6.9	3.9	3.7	3.7
DT Supply Fan BTUH *		20487	11580	10986	10986
DT Supply Fan Rise		1.3	0.8	0.7	0.7
Duct Rise Allowance		0.5	0.5	0.5	0.5
Supply Air DB	H	51.7	50.1	49.6	47.7
Supply Air "h"		21.98	21.65	21.52	20.23

Ln (h)		3.090	3.075	3.069	3.007
Supply Air lb/lb		0.0088	0.0089	0.0089	0.0081
Supply Air WB		53.0	52.4	52.2	49.9
Avail Space Sens Cap'y		374.2	400.1	406.7	436.7
Avail Space Latent Cap'y		52.9	47.9	49.9	100.9
Space Sens Load		309	309	309	309
Unit XS/Short		21.3%	29.7%	31.8%	41.5%
Space Latent Load		29	29	29	29
Unit XS/Short		81.2%	64.0%	70.9%	245.5%
* Fan BTUH includes 5% belt and drive losses					
and 90% motor efficiency					
LOAD SUMMARY					
Space Sensible Heat		308.6	308.6	308.6	308.6
Duct Rise Allowance		7.7	7.7	7.7	7.7
Plenum Heat		0.0	0.0	0.0	0.0
Return Fan Heat		0.0	0.0	0.0	0.0
Supply Fan Heat		20.5	11.6	11.0	11.0
Outside Air Sensible		25.6	25.6	25.6	25.6
MACHINE SENSIBLE		362.4	353.5	352.9	352.9
Space Latent		29.2	29.2	29.2	29.2
Outside Air Latent		74.1	74.1	74.1	74.1
MACHINE LATENT		103.3	103.3	103.3	103.3
MACHINE TOTAL LOAD (MBH)		465.7	456.8	456.2	456.2
TONS		39	38	38	38
MACHINE SHR		0.78	0.77	0.77	0.77
OA WB(K)		296.5	296.5	296.5	296.5
OA Part Vapor Press		0.358	0.358	0.358	0.358
OA Sat'd Vapor Press		0.415	0.415	0.415	0.415
OA "h"		37.44	37.44	37.44	37.44

Appendix I: LEED Analysis

In the LEED Analysis, assumptions were made due to limitations with available information.

LEED v4 for BD+C: New Construction and Major Renovation

Project Checklist

Gateway Campus Center

3/4/2016 Submittal

Y	?	N				
Y	1		Credi 1	Integrative Process	1	
			Location and Transportation		Possible Points: 16	
	0	N	Credit 1	LEED for Neighborhood Development Location	16	
Y	1		Credit 2	Sensitive Land Protection	1	Brownfield remediation
Y	2		Credit 3	High Priority Site	2	Brownfield remediation
Y	2		Credit 4	Surrounding Density and Diverse Uses	5	Option 2 Diverse Uses
Y	3		Credit 5	Access to Quality Transit	5	*assumption 144 weekday
Y	1		Credit 6	Bicycle Facilities	1	Case 1
Y	1		Credit 7	Reduced Parking Footprint	1	
	0	N	Credit 8	Green Vehicles	1	
			Sustainable Sites		Possible Points: 10	
Y			Prereq 1	Construction Activity Pollution Prevention	Required	
Y	1		Credit 1	Site Assessment	1	*assume site survey was completed
Y	2		Credit 2	Site Development--Protect or Restore Habitat	2	*assumption
Y	1		Credit 3	Open Space	1	pedestrian-oriented
Y	1		Credit 4	Rainwater Management	3	Nothing in our design, could be assumed
	0	N	Credit 5	Heat Island Reduction	2	
	0	N	Credit 6	Light Pollution Reduction	1	
			Water Efficiency		Possible Points: 11	
Y			Prereq 1	Outdoor Water Use Reduction	Required	
Y			Prereq 2	Indoor Water Use Reduction	Required	
Y			Prereq 3	Building-Level Water Metering	Required	
Y	2		Credit 1	Outdoor Water Use Reduction	2	*assumption

Y	?	N	Credit	Name	Points	Notes
Y	2		Credit 2	Indoor Water Use Reduction	6	Didn't Design to this level of detail, assume 2 points
Y	1		Credit 3	Cooling Tower Water Use	2	
Y	1		Credit 4	Water Metering	1	Irrigation and indoor plumbing fixtures
			Energy and Atmosphere		Possible Points: 33	
Y			Prereq 1	Fundamental Commissioning and Verification	Required	
Y			Prereq 2	Minimum Energy Performance	Required	
Y			Prereq 3	Building-Level Energy Metering	Required	
Y			Prereq 4	Fundamental Refrigerant Management	Required	
Y	3		Credit 1	Enhanced Commissioning	6	Path 1
Y	6		Credit 2	Optimize Energy Performance	18	option 2
Y	1		Credit 3	Advanced Energy Metering	1	assumption that we will install meters
Y	1		Credit 4	Demand Response	2	assumption
		N	Credit 5	Renewable Energy Production	3	
Y	1		Credit 6	Enhanced Refrigerant Management	1	assumption that we use refrigerant with depleted affects on the ozone
		N	Credit 7	Green Power and Carbon Offsets	2	
			Materials and Resources		Possible Points: 13	
Y			Prereq 1	Storage and Collection of Recyclables	Required	
Y			Prereq 2	Construction and Demolition Waste Management Planning	Required	
Y	5		Credit 1	Building Life-Cycle Impact Reduction	5	Option 4
Y	1		Credit 2	Building Product Disclosure and Optimization - Environmental Product Declarations	2	
Y	1		Credit 3	Building Product Disclosure and Optimization - Sourcing of Raw Materials	2	probably Option 1?
Y	1		Credit 4	Building Product Disclosure and Optimization - Material Ingredients	2	
Y	2		Credit 5	Construction and Demolition Waste Management	2	*assumption
			Indoor Environmental Quality		Possible Points: 16	
Y			Prereq 1	Minimum Indoor Air Quality Performance	Required	
Y			Prereq 2	Environmental Tobacco Smoke Control	Required	
	1		Credit 1	Enhanced Indoor Air Quality Strategies	2	probably Option 2, some assumptions were made

Y	3		Credit 2	Low-Emitting Materials	3	paints, adhesives, flooring, composite wood, ceilings, furniture
Y	1		Credit 3	Construction Indoor Air Quality Management Plan	1	*assumption that IAQ management plan was made
Y	1		Credit 4	Indoor Air Quality Assessment	2	*assumption Option 1 Path 2
Y	1		Credit 5	Thermal Comfort	1	Option 1
Y	2		Credit 6	Interior Lighting	2	
Y	2		Credit 7	Daylight	3	55% sDA, assume computer simulation
Y	1		Credit 8	Quality Views	1	
		N	Credit 9	Acoustic Performance	1	

			Innovation	Possible Points:	6
Y	3		Credit 1 Innovation		5
	0	N	Credit 2 LEED Accredited Professional		1

			Regional Priority	Possible Points:	4
	0	N	Credit 1 Regional Priority: Specific Credit		1
	0	N	Credit 2 Regional Priority: Specific Credit		1
	0	N	Credit 3 Regional Priority: Specific Credit		1
	0	N	Credit 4 Regional Priority: Specific Credit		1

59			**Total**	Possible Points:	110

Certified 40 to 49 points Silver 50 to 59 points Gold 60 to 79 points Platinum 80 to 110

Appendix J: Trox DID632A Active Chilled Beam Data

Dimensional data

Characteristics

- Primary airflow range from 45 to 360 cfm
- For mounting heights of 8 to 15 ft
- Flush ceiling installation
- Side (standard) or top-entry primary air connection
- Lengths of 4, 6, 8 and 10ft (other lengths on request, cost option)
- Integrates into most ceiling systems
- Nozzles in three sizes to optimize induction (see table below)
- Heat exchangers for two- or four-pipe systems
- Maximum operating pressure: 250 psi
- Maximum operating temperature: 165˚F - 200˚F (other operating pressures and temperatures upon request)

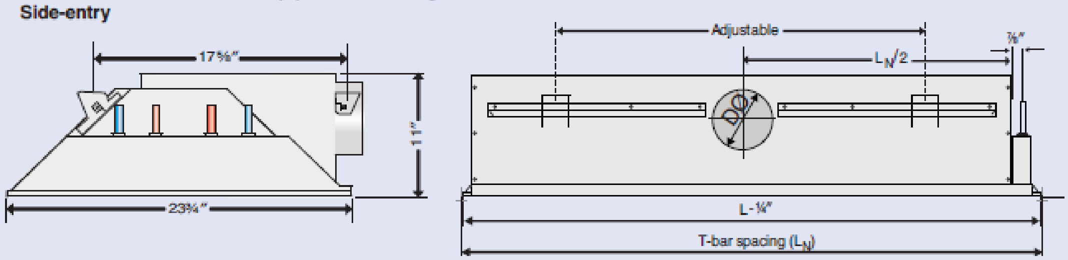
Construction features

- Primary air connections suitable for circular connecting ducts
- 4 or 6 sliding hanging brackets (dependent on beam length) for on-site installation (brackets can be mechanically locked in position)
- Water connections on the top near either end

Materials

- Casing, nozzle plate, hanging rails and primary air connection made of powder-coated sheet steel
- Hanging brackets of galvanized sheet steel
- Perforated induction grille (option LR) made from powder-coated sheet steel
- Linear bar induction grille (option GL) made from aluminum (cost option)
- Heat exchanger made of copper tubes and formed aluminum fins
- Heat exchanger natural finish (standard) or flat black (cost option)
- Visible surfaces powder-coated white (RAL 9010) as standard or alternative RAL color as cost option

Standard construction with 4-pipe heat exchanger
Side-entry



Standard border (Type 0) shown is designed for flush mounting in a 9/16" or 15/16" T-bar ceiling grid.

Optional border styles are shown below.

Available nominal lengths (L_N): See table at right

Beam height: 11"

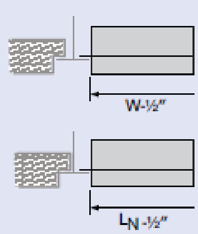
DID632A
Dimensions by nozzle type

Beam Length	Nozzle Type G DØ	Nozzle Type H DØ	Nozzle Type U DØ
4′	4⅞″	5⅞″	5⅞″
5′	5⅞″	7⅞″	7⅞″
6′			
7′	7⅞″		
8′			
9′			
10′			

T-BAR BORDER STYLE OPTIONS

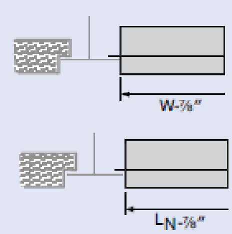
Type B1

Designed for flush mounting with tegular ceiling tiles for use in a 9/16" wide t-bar grid.



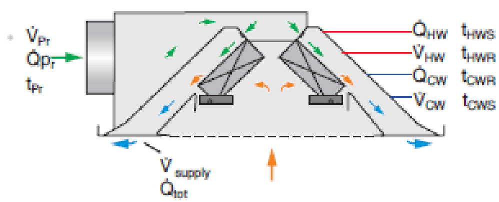
Type B2

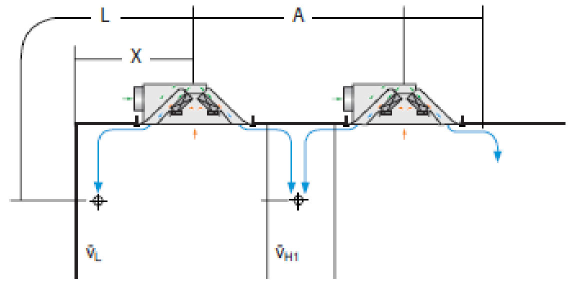
Designed for flush mounting with tegular ceiling tiles for use in a 15/16" wide t-bar grid.



4

Nomenclature · Performance notes





$\dot{Q}_{SEN}$	in	Btu/h:	Space sensible load
$\dot{Q}_{LAT}$	in	Btu/h:	Space latent load
$\dot{V}_{Pr}$	in	cfm:	Primary airflow rate to offset space latent gains
$\dot{V}_{HW}$	in	gpm:	Water volume flow rate, heating
$\dot{V}_{CW}$	in	gpm:	Water volume flow rate, cooling
$\dot{V}_{supply}$	in	cfm:	Discharge flow rate
$\dot{Q}p_r$	in	Btu/h:	Primary air cooling capacity
$\dot{Q}_{HW}$	in	Btu/h:	Water heating capacity
$\dot{Q}_{CW}$	in	Btu/h:	Water cooling capacity
$\dot{Q}_{tot}$	in	Btu/h:	Total beam thermal capacity
W_{ROOM}	in	gr:	Room humidity ratio
Wp_r	in	gr:	Primary air humidity ratio
Δw	in	gr:	Difference between room and primary air humidity ratio
Δt_{Pr}	in	°F:	Difference between room air and primary air temperature
Δt_W	in	°F:	Supply to return water temperature difference
Δt_{RW}	in	°F:	Difference between room air and water supply temperature
Δp_t	in	in. H_2O:	Air pressure drop
Δp_W	in	ft. H_2O:	Water pressure drop
t_R	in	°F:	Room temperature
t_{HWS}	in	°F:	Water supply temperature, heating
t_{HWR}	in	°F:	Water return temperature, heating
t_{CWS}	in	°F:	Water supply temperature, cooling
t_{CWR}	in	°F:	Water return temperature, cooling
t_{Pr}	in	°F:	Primary air temperature
$\bar{v}_L$	in	fpm:	Air velocity distance L
$\bar{v}_{H1}$	in	fpm:	Air velocity distance H_1
A	in	ft:	Spacing between two diffusers with opposing blow patterns
L	in	ft:	Horizontal and vertical distance ($x+H_1$) discharge to the wall
H_1	in	ft:	Distance from ceiling to occupied zone (5´ 6˝ above the floor)
Δt_o	in	ft:	Temperature difference room air and beam discharge temperature

	Coil Water Flow Rate, GPM					
	0.50	0.75	1.00	1.25	1.50	2.00
Multiply Q_{CW} or Q_{HW} by:	0.71	0.85	0.92	0.97	1.00	1.04
Multiply Δp_w in table by:	0.11	0.25	0.46	0.71	1.00	1.79

Table 1: Corrections for other water flow rates

Useful equations:

$$\dot{Q}p_r = 1.09 \times \dot{V}_{Pr} \times (t_R - t_{Pr})^*$$
$$\Delta t_W = \dot{Q}_W / (500 \times \dot{V}_W)$$

*$\dot{Q}p_r$ equation is based on standard air

	t_R - t_{CWS}					
	10	12	14	16	18	20
Multiply Q_{CW} by:	0.58	0.67	0.78	0.89	1.00	1.11

Table 2a: Corrections for other chilled water supply temperatures

	t_{HWS} - t_R					
	20-	30	40	50	60	70
Multiply Q_{HW} by:	0.40	0.60	0.80	1.00	1.20	1.40

Table 2b: Corrections for other hot water supply temperatures

Quick selection table

Reference Values - Cooling

t_R	75 °F	t_{CWS}	57 °F
t_{Pr}	55 °F	$\dot{V}_{CW}$	1.50 GPM

Reference Values - Heating

t_R	70 °F	t_{HWS}	120 °F
t_{Pr}	55 °F		

Active Length	Nozzle Type	Primary Air		Cooling Two-pipe system			Cooling Four-pipe system			Heating Four-pipe system			Isothermal Throw[6]	NC[7]
		$\dot{V}pr$	Δp_t	$\dot{Q}_{tot}$[1]	$\dot{Q}_{CW}$[2]	Δp_w[3]	$\dot{Q}_{tot}$[1]	$\dot{Q}_{CW}$[2]	Δp_w[3]	$\dot{Q}_{NET}$[4]	$\dot{V}_{HW}$[5]	Δp_w[3]		
ft		CFM	in. H_2O	Btu/h	Btu/h	ft. H_2O	Btu/h	Btu/h	ft. H_2O	Btu/h	GPM	ft. H_2O	ft.	
4	G	45	0.22	2948	1968	1.5	2781	1801	0.9	3817	1.15	1.6	3-4-6	18
		65	0.46	4048	2633		3830	2415		5204	1.50	2.8	4-6-9	22
		85	0.79	4946	3096		4695	2844		5999	1.50	2.8	5-7-12	27
	H	65	0.23	3696	2281		3504	2089		4354	1.50	2.8	4-5-7	19
		90	0.45	4741	2782		4512	2553		5154	1.50	2.8	5-6-10	23
		115	0.73	5649	3146		5394	2890		5628	1.50	2.8	6-8-14	26
	U	80	0.22	4132	2390		3932	2191		4372	1.50	2.8	4-5-8	19
		110	0.42	5232	2838		4999	2605		4962	1.50	2.8	5-7-12	23
		140	0.68	6214	3166		5957	2909		5267	1.50	2.8	6-8-15	30
6	G	85	0.36	5282	3432	2.1	5007	3156	1.2	6817	1.50	3.9	4-5-8	24
		105	0.55	6228	3943		5918	3632		7739	1.50	3.9	4-6-10	30
		125	0.78	7069	4348		6732	4011		8408	1.50	3.9	5-7-11	35
	H	100	0.23	5514	3337		5245	3068		6340	1.50	3.9	4-5-8	19
		140	0.45	7091	4043		6774	3726		7411	1.50	3.9	5-7-11	24
		180	0.75	8461	4543		8112	4194		7988	1.50	3.9	6-8-14	27
	U	130	0.24	6420	3590		6134	3304		6465	1.50	3.9	4-6-9	21
		180	0.47	8125	4206		7797	3878		7156	1.50	3.9	5-7-13	25
		230	0.76	9656	4649		9300	4293		7430	1.50	3.9	7-9-17	31
8	G	110	0.33	6694	4299	2.8	6360	3966	1.6	8535	1.50	5.1	4-5-7	23
		140	0.53	8061	5013		7683	4635		9810	1.50	5.1	4-6-10	29
		170	0.78	9257	5556		8848	5147		10673	1.50	5.1	5-7-12	35
	H	140	0.26	7451	4403		7111	4063		8299	1.50	5.1	4-5-8	21
		190	0.47	9314	5178		8927	4791		9400	1.50	5.1	5-7-11	25
		240	0.76	10961	5736		10542	5317		9975	1.50	5.1	6-8-14	31
	U	150	0.20	7501	4235		7171	3906		7721	1.50	5.1	4-5-8	20
		220	0.42	9926	5137		9541	4752		8805	1.50	5.1	5-7-12	27
		290	0.73	12057	5744		11638	5324		9174	1.50	5.1	7-9-16	38
10	G	120	0.26	7289	4677	3.6	6932	4320	2.1	9304	1.50	6.5	3-5-7	24
		150	0.41	8737	5472		8333	5068		10790	1.50	6.5	4-5-8	30
		180	0.59	9999	6081		9562	5643		11826	1.50	6.5	5-6-10	35
	H	170	0.25	8901	5200		8513	4812		9784	1.50	6.5	4-5-8	22
		230	0.46	11094	6087		10656	5649		11021	1.50	6.5	5-7-11	28
		290	0.72	13033	6719		12563	6250		11636	1.50	6.5	6-8-14	35
	U	180	0.20	8897	4978		8521	4603		9067	1.50	6.5	4-5-7	22
		250	0.38	11324	5881		10897	5454		10176	1.50	6.5	5-6-10	31
		320	0.63	13479	6513		13020	6053		10620	1.50	6.5	6-8-14	40

PERFORMANCE NOTES:

[1] $\dot{Q}_{tot}$ includes $\dot{Q}_{CW}$ plus sensible cooling provided by primary air 20°F below room temperature at the flow rate indicated.
[2] $\dot{Q}_{CW}$ is coil sensible cooling using 1.50 GPM of chilled water supplied 18°F below the room temperature.
[3] Δp_W is the water head loss at the referenced water supply flow rate.
[4] $\dot{Q}_{NET}$ is coil heating using referenced hot water flow rate supplied 50°F above the room temperature.
[5] $\dot{V}_{HW}$ is hot water flow rate limited to the lesser of 1.5 GPM or that which results in a supply to room air temperature differential not exceeding 20°F.
[6] Isothermal throw values presented to 150, 100 and 50 FPM, indicated as VH_1 in selection program.
[7] NC values are based on a room absorption of 10 dB (per octve band) re 10^{-12} watts.

Selection Software
For detailed selections, designers may download the TROX chilled beam selection software at www.troxusa.com. This software (see sample below) affords easy access to the beams' performance data against user defined parameters.

User defined input parameters include:
- Beam length and nozzle type
- Water flow rates and supply temperatures
- Primary airflow rate, temperature and RH
- Room temperature and RH%
- Room height, beam spacing, distance to walls and occupied zone height

Upon entry of these parameters, the software returns values for:
- Air and water pressure requirements
- Sensible and latent cooling and/or heating capacity
- Return water temperature
- Waterside pressure loss
- Resultant noise (NC) levels
- Local velocities and temperatures in the occupied zone

NOTE: Macros must be enabled for the spreadsheet to function.

Selection Software Example

TROX Chilled Beam Selection Program

Save to Schedule

Input DID	4 pipe coil		2 pipe coil	
	cooling	heating	cooling	heating
Vwater DID	1.00 GPM	1.00 GPM		
Unit length	4.0 ft			
Nozzle-type	G			
Vair-primary DID	75 CFM			
Connection-diameter / primary air	5 in			

Project	Room-No.	Comment

Input Temperatures	cooling		heating	
Tprimary air / rel. Humidity	55.0 °F	80.0 %	55.0 °F	80.0 %
Troom / rel. Humidity	75.0 °F	50.0 %	70.0 °F	50.0 %
Twater-flow	58.0 °F		120.0 °F	
Maximum head loss in water coil	10 ft WG			

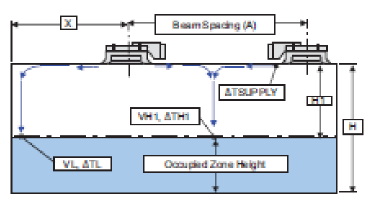
Input Room Dimensions		Altitude
Room Height (H)	10.0 ft	0 ft
A	10.0 ft	Additive
X	5.0 ft	None
Occupied Zone Height	5.0 ft	0%

TROX® TECHNIK
The art of handling air

Restore Standard Inlet Size

Model Type: DID632A

Piping and Operation: 4 Pipe (Heating and Cooling)



Results	4 pipe coil		2 pipe coil	
	cooling	heating	cooling	heating
Δtwater	-4.7 °F	13.0 °F		
Twater-return	62.7 °F	107.0 °F		
ΔT room - water flow	12.3 °F	-37.0 °F		
ΔT Room water average	14.6 °F	-43.5 °F		
Qwater DID	-2357 BTUH	6503 BTUH		
Qair DID	-1633 BTUH	-1230 BTUH		
Q DID	-3990 BTUH	5273 BTUH		
ΔP water	0.4 ft WG	1.2 ft WG		
ΔP air	0.62 inch WG			
NC (incl. 10 dB room absorbtion)	24			

NOTE: This calculation program is only applicable to chilled beams manufactured by TROX USA.

Terminal Velocities and Temperatures			
vL2 (measured 2" from wall)	78 FPM	40 FPM	
vL6 (measured 6" from wall)	47 FPM	24 FPM	
vH1	39 FPM		
ΔTL	-2.3 °F	0.8 °F	
ΔTH1	-8.9 °F		
ΔTsupply	-12.6 °F	16.6 °F	
Beam supply airflow rate	293 CFM		
Latent cooling of primary air	-687 BTUH	-162 BTUH	
Beam model and coil type	TROX DID632A		TROX DID632A

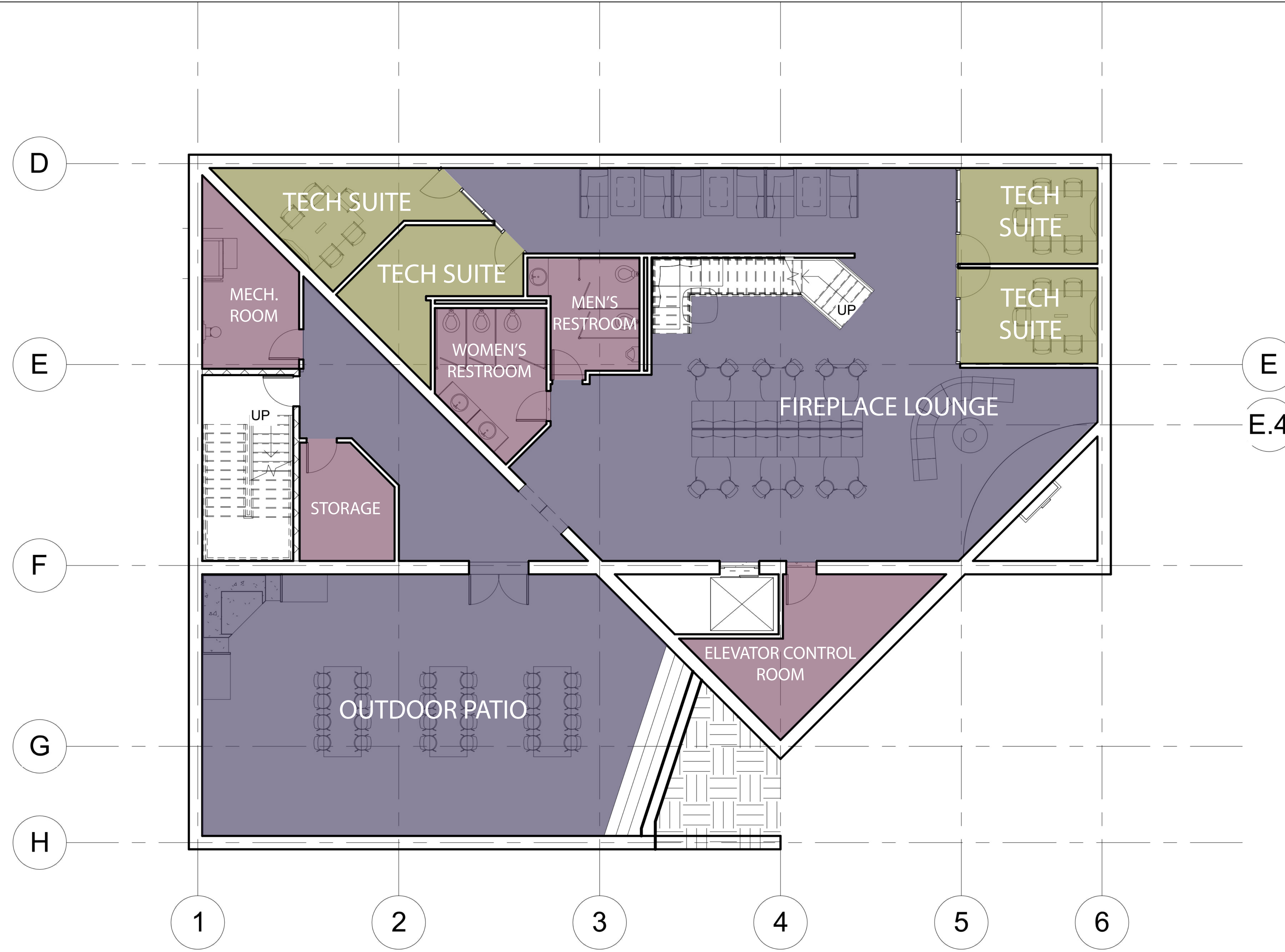
Support Values	
N-nozzles total	90
Aeff	0.025598 ft²
veff	2930 FPM
H1	5.0 ft
L	10.0 ft
Room Air Dew Point - Cooling	55.1 °F
Primary Air Dew Point - Cooling	49.0 °F

TROX USA, Inc
4305 Settingdown Circle
Cumming, GA 30028
Phone: (770) 569-1433
Fax: (770) 569-1435
www.TROXUSA.com

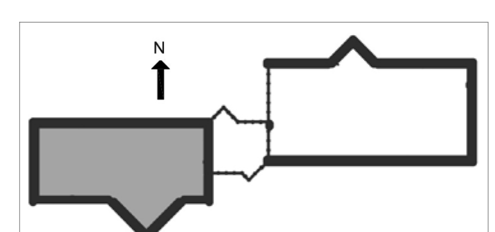
Version 1.03
5/23/2013

Text in red represents a value that is not generally recommended (see user notes for details).

Appendix K: Drawings



Gateway Campus Center

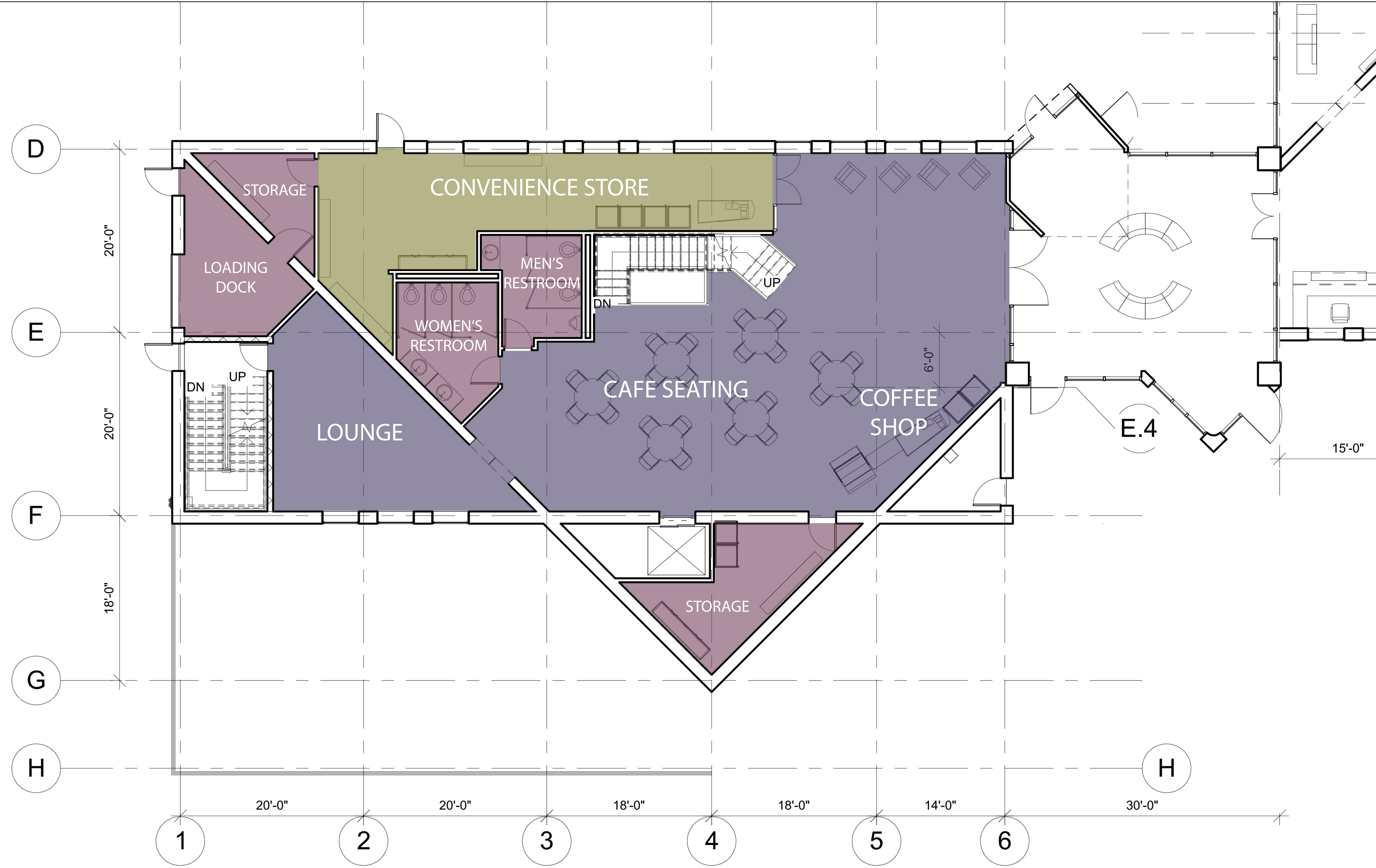


No.	Description	Date

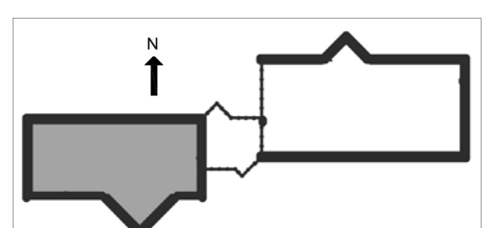
Basement Floor - Administration

Project number	Project Number	A-100
Date	3/23/16	
Drawn by	EEM, JEP	
Checked by	CHK	Scale 3/32" = 1'-0"

3/23/16



Gateway Campus Center



No.	Description	Date

First Floor - Administration

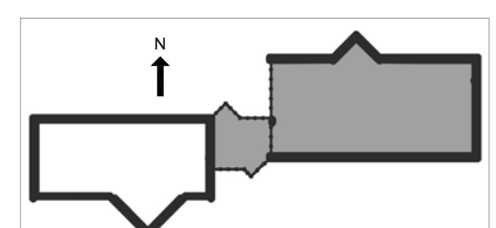
Project number	Project Number
Date	3/23/16
Drawn by	EEM, JEP
Checked by	CHK

A-101

Scale 3/32" = 1'-0"

3/23/16

Gateway Campus Center



No.	Description	Date

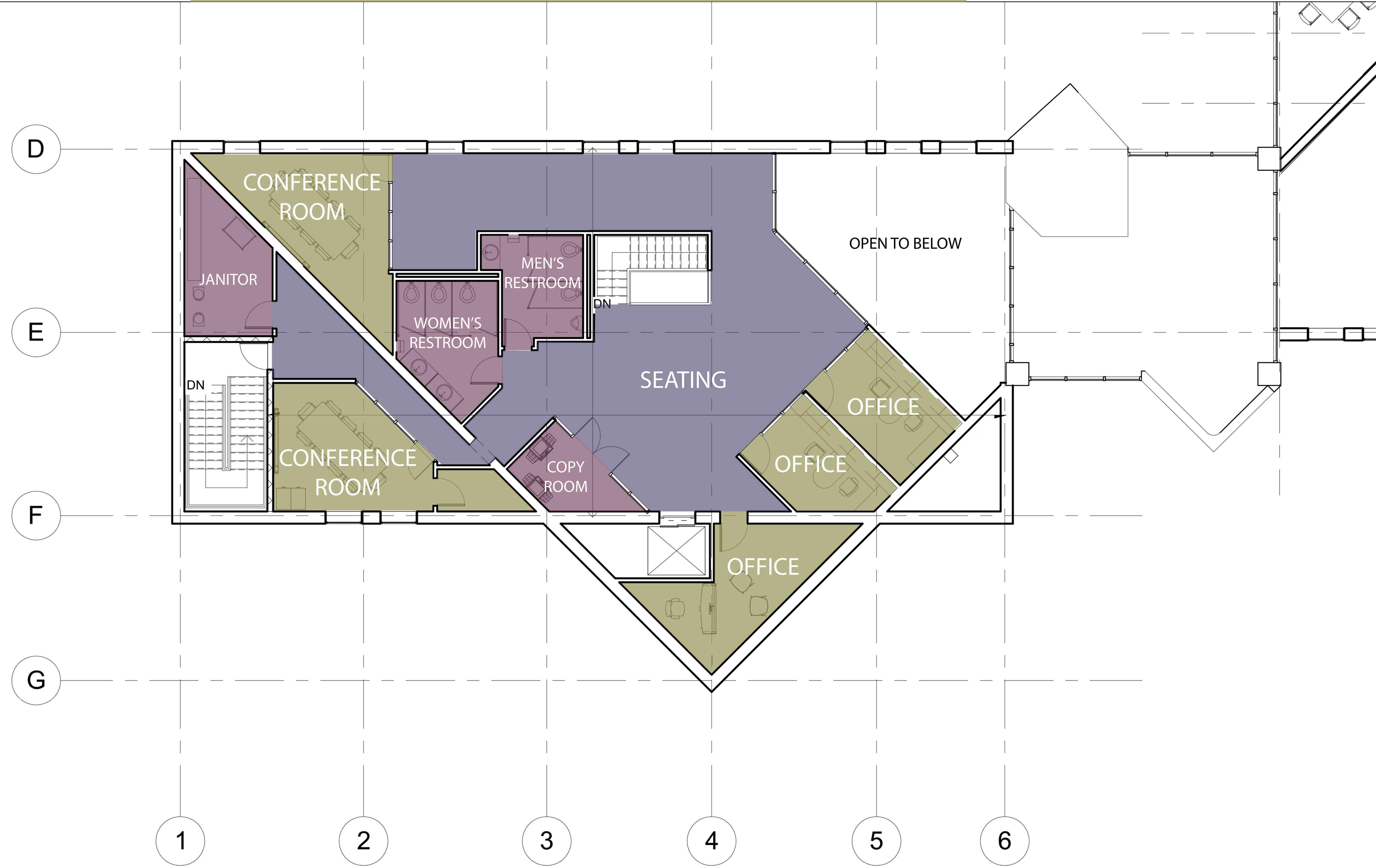
First Floor - Student

Project number	Project Number
Date	3/23/16
Drawn by	EEM, JEP
Checked by	CHK

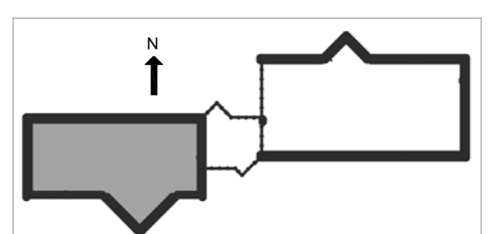
A-102

Scale 3/32" = 1'-0"

3/23/16



Gateway Campus Center



No.	Description	Date

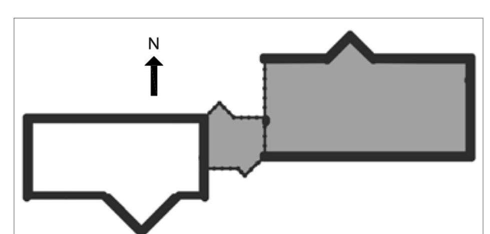
Second Floor - Administration

Project number	Project Number	A-103
Date	3/23/16	
Drawn by	EEM, JEP	
Checked by	CHK	Scale 3/32" = 1'-0"

3/23/16

WPI

Gateway Campus Center



No.	Description	Date

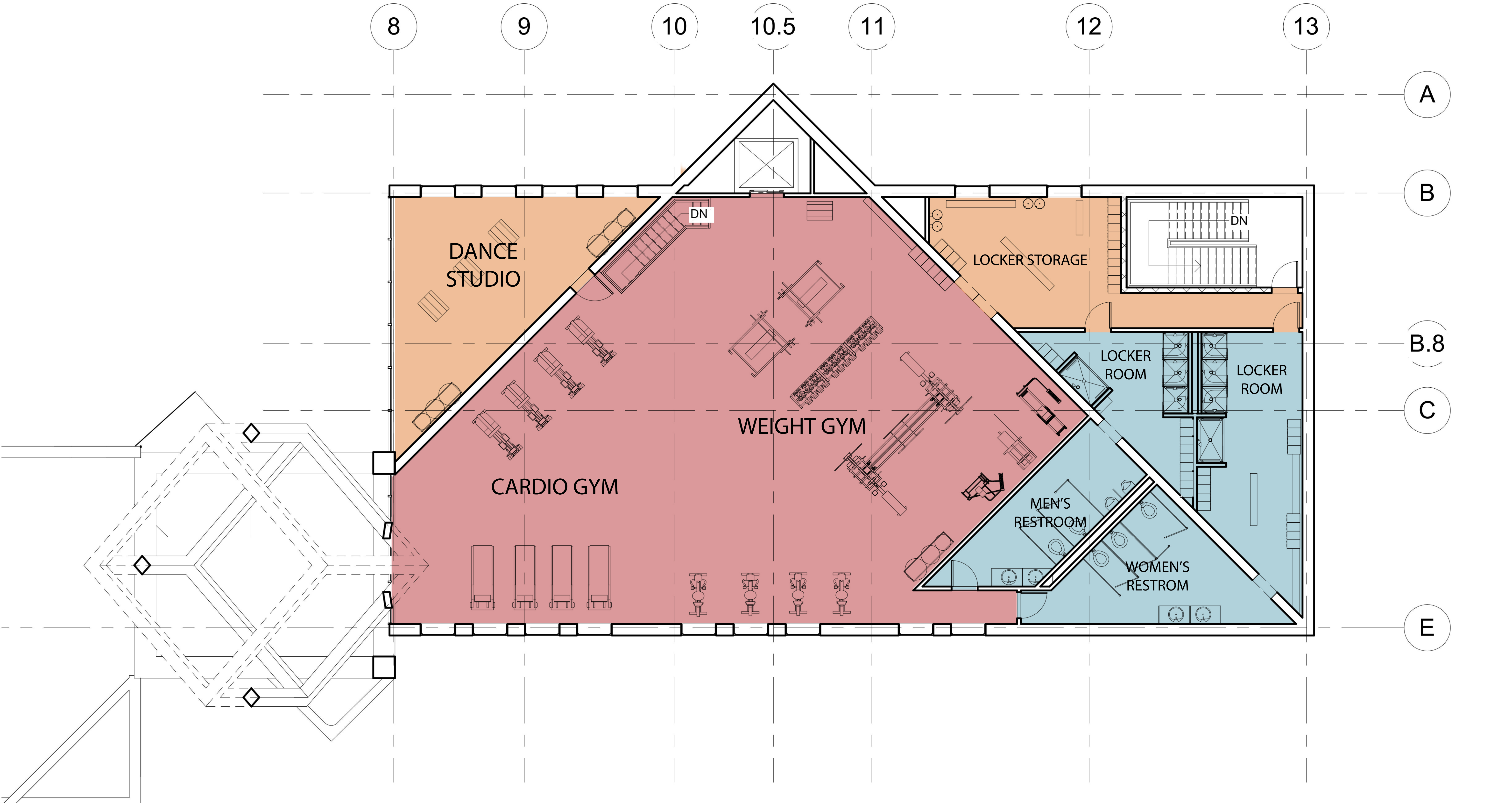
Second Floor - Student

Project number	Project Number
Date	3/23/16
Drawn by	EEM, JEP
Checked by	CHK

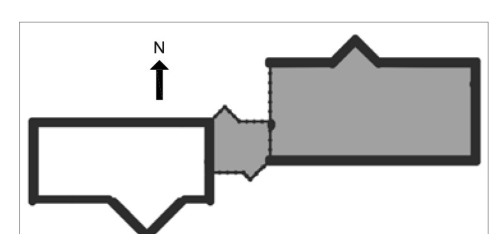
A-104

Scale 3/32" = 1'-0"

3/23/16



Gateway Campus Center



No.	Description	Date

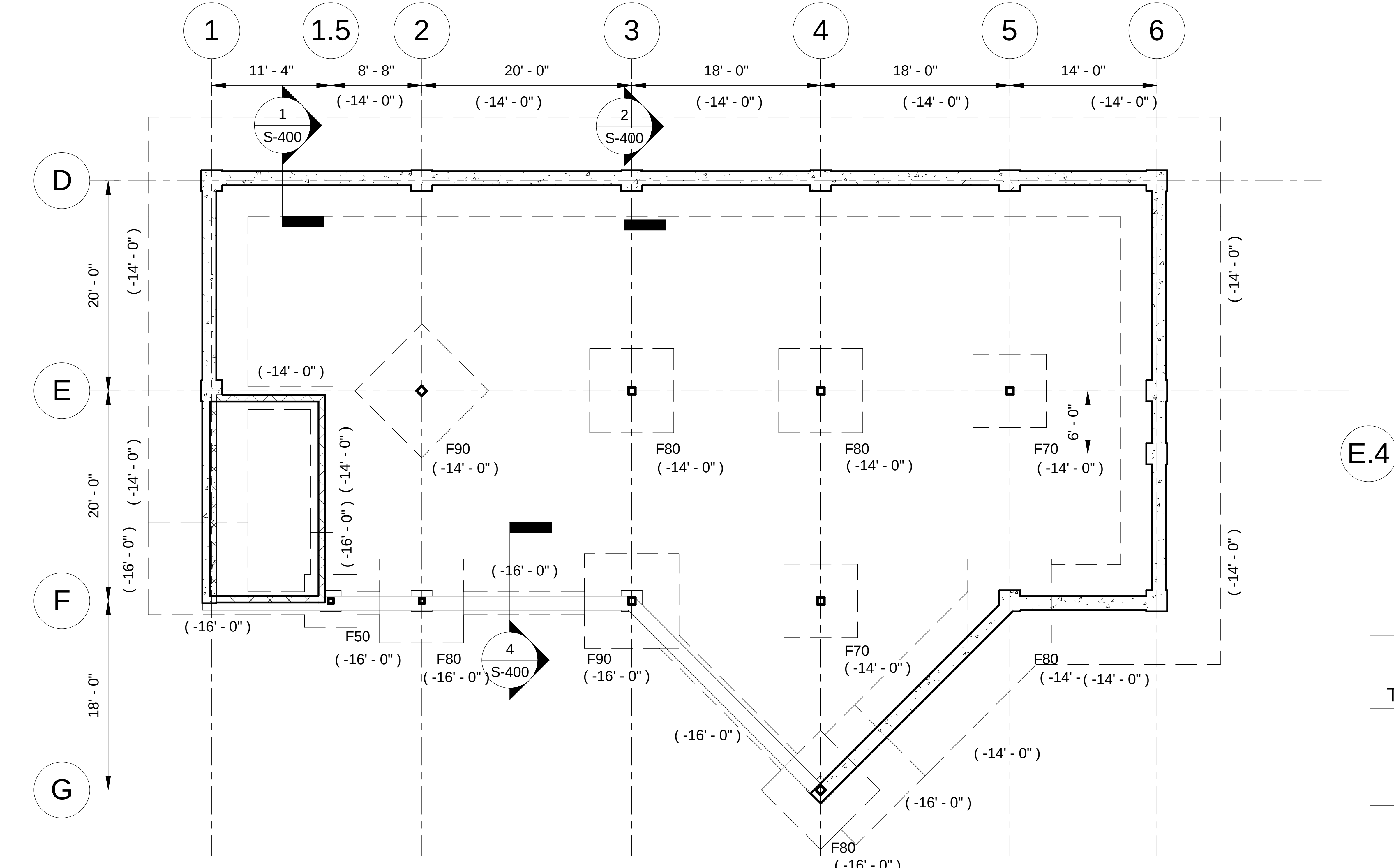
Third Floor - Student

Project number	Project Number
Date	3/23/16
Drawn by	EEM, JEP
Checked by	CHK

A-105

Scale 3/32" = 1'-0"

3/23/16



1 FOUNDATION PLAN - ADMINISTRATION
3/32" = 1'-0"

1. TOP OF SLAB ELEVATION = -13'-0"
2. FLOOR CONSTRUCTION: 5" NORMAL WEIGHT CONCRETE SLAB REINFORCED WITH 6x6-W2.9xW2.9 WELDED WIRE FABRIC
3. (#'-#") INDICATES TOP OF FOOTING ELEVATION FROM (0'-0")

FOOTING SCHEDULE

TYPE	SIZE	REINFORCEMENT
F50	5'-0"x5'-0"x12"	(6)-#5 BOTTOM EACH WAY
F60	6'-0"x6'-0"x18"	(8)-#6 BOTTOM EACH WAY
F70	7'-0"x7'-0"x18"	(7)-#7 BOTTOM EACH WAY
F80	8'-0"x8'-0"x24"	(10)-#8 BOTTOM EACH WAY
F90	9'-0"x9'-0"x24"	(10)-#8 BOTTOM EACH WAY

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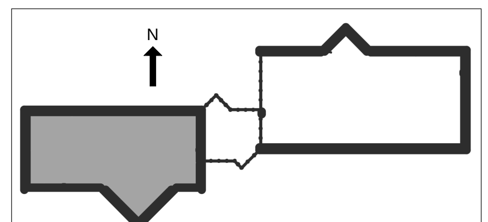
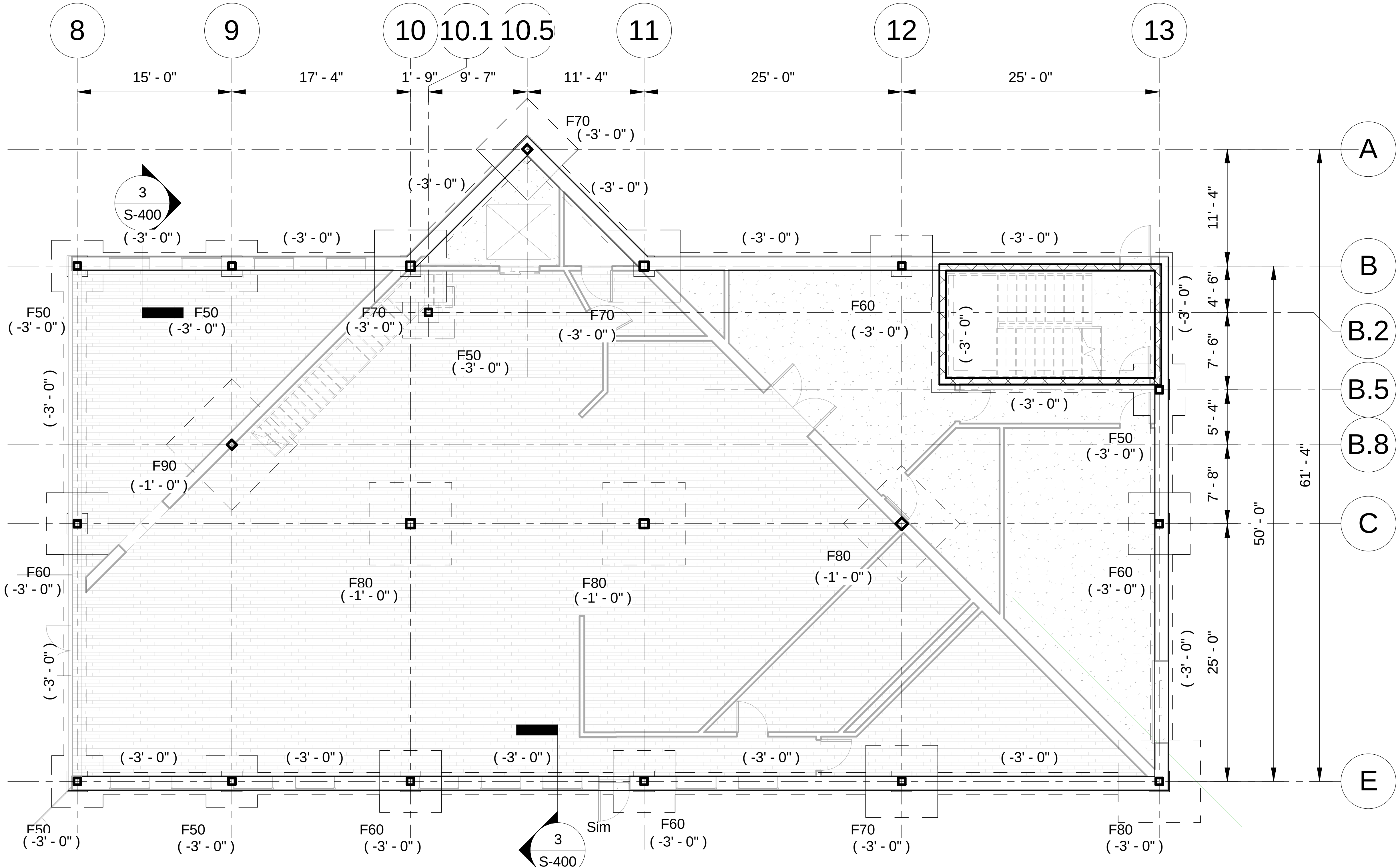


No.	Description	Date

FOUNDATION - ADMIN

Project number	Project Number	S-100
Date	3/3/16	
Drawn by	JDS	
Checked by	Checker	Scale 3/32" = 1'-0"

3/24/2016 1:00:36 AM



1 FOUNDATION PLAN - STUDENT
3/32" = 1'-0"

1. TOP OF SLAB ELEVATION = 0'-0"
2. FLOOR CONSTRUCTION: 5" NORMAL WEIGHT CONCRETE SLAB REINFORCED WITH 6x6-W2.9xW2.9 WELDED WIRE FABRIC
3. (#'-#") INDICATES TOP OF FOOTING ELEVATION FROM (0'-0")

FOOTING SCHEDULE

TYPE	SIZE	REINFORCEMENT
F50	5'-0"x5'-0"x12"	(6)-#5 BOTTOM EACH WAY
F60	6'-0"x6'-0"x18"	(8)-#6 BOTTOM EACH WAY
F70	7'-0"x7'-0"x18"	(7)-#7 BOTTOM EACH WAY
F80	8'-0"x8'-0"x24"	(10)-#8 BOTTOM EACH WAY
F90	9'-0"x9'-0"x24"	(10)-#8 BOTTOM EACH WAY

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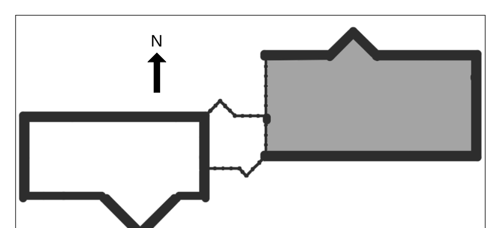

No.	Description	Date

FOUNDATION - STUDENT

Project number	Project Number	S-101
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Drawn by	JDS	
Checked by	Checker	Scale 3/32" = 1'-0"

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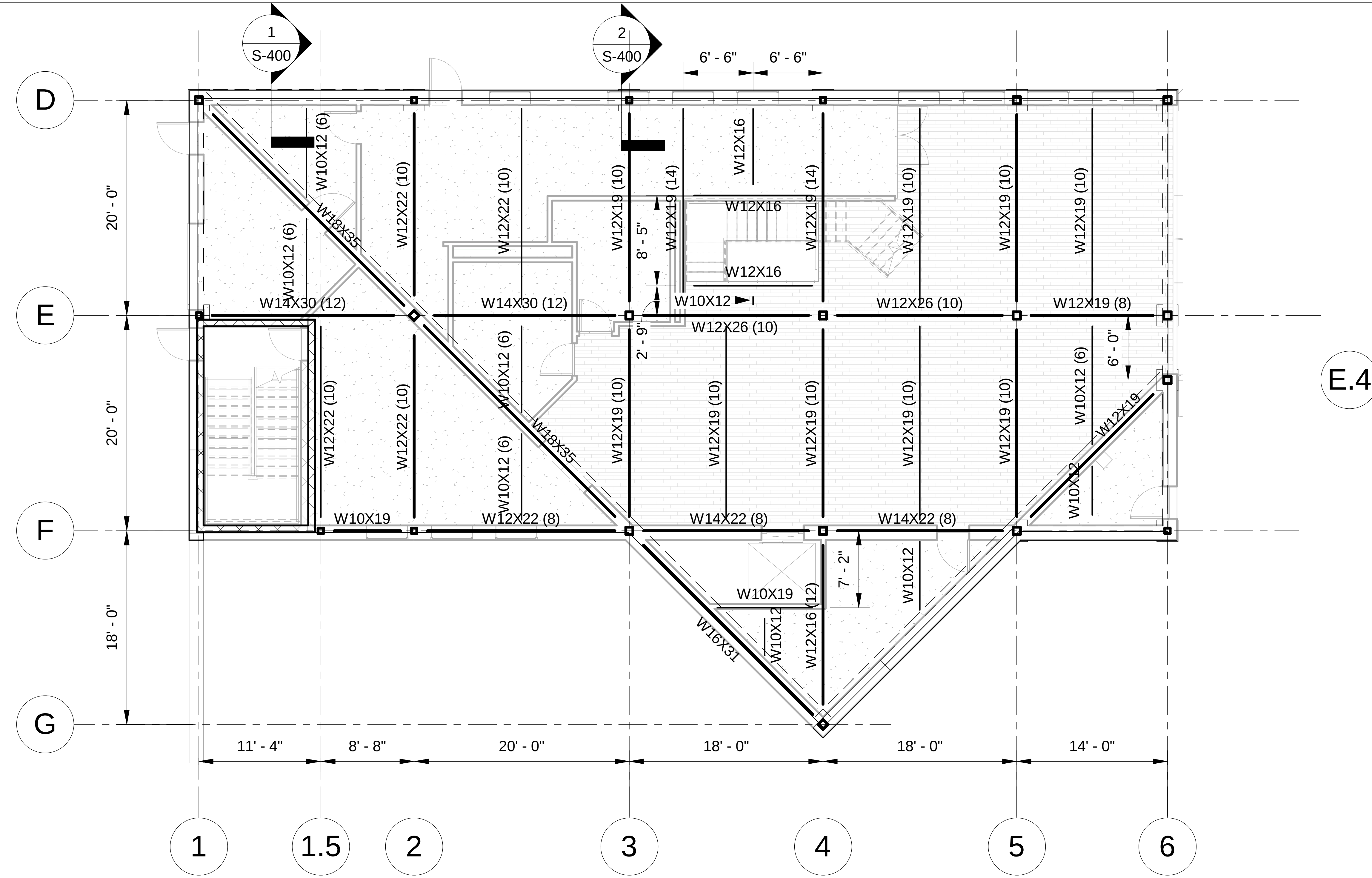

1 FIRST FLOOR - ADMINISTRATION
3/32" = 1'-0"

1. TOP OF SLAB ELEVATION = 0'-0"
2. TOP OF STEEL ELEVATION = (-0'-6 1/2") FROM TOP OF SLAB
3. FLOOR CONSTRUCTION: 3 1/2" NORMAL WEIGHT CONCRETE ON 3" 20ga. COMPOSITE METAL FLOOR DECK REINFORCED WITH 6x6-W2.1xW2.1 W.W.F.
4. (##) - INDICATES THE NUMBER OF 3/4" DIA. x 5" LONG SHEAR STUDS UNIFORMLY SPACED ALONG THE BEAM

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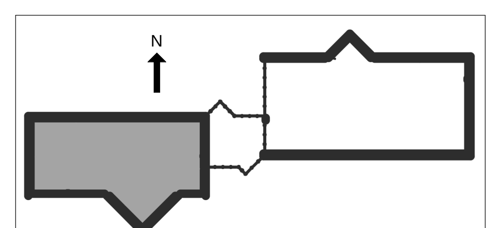
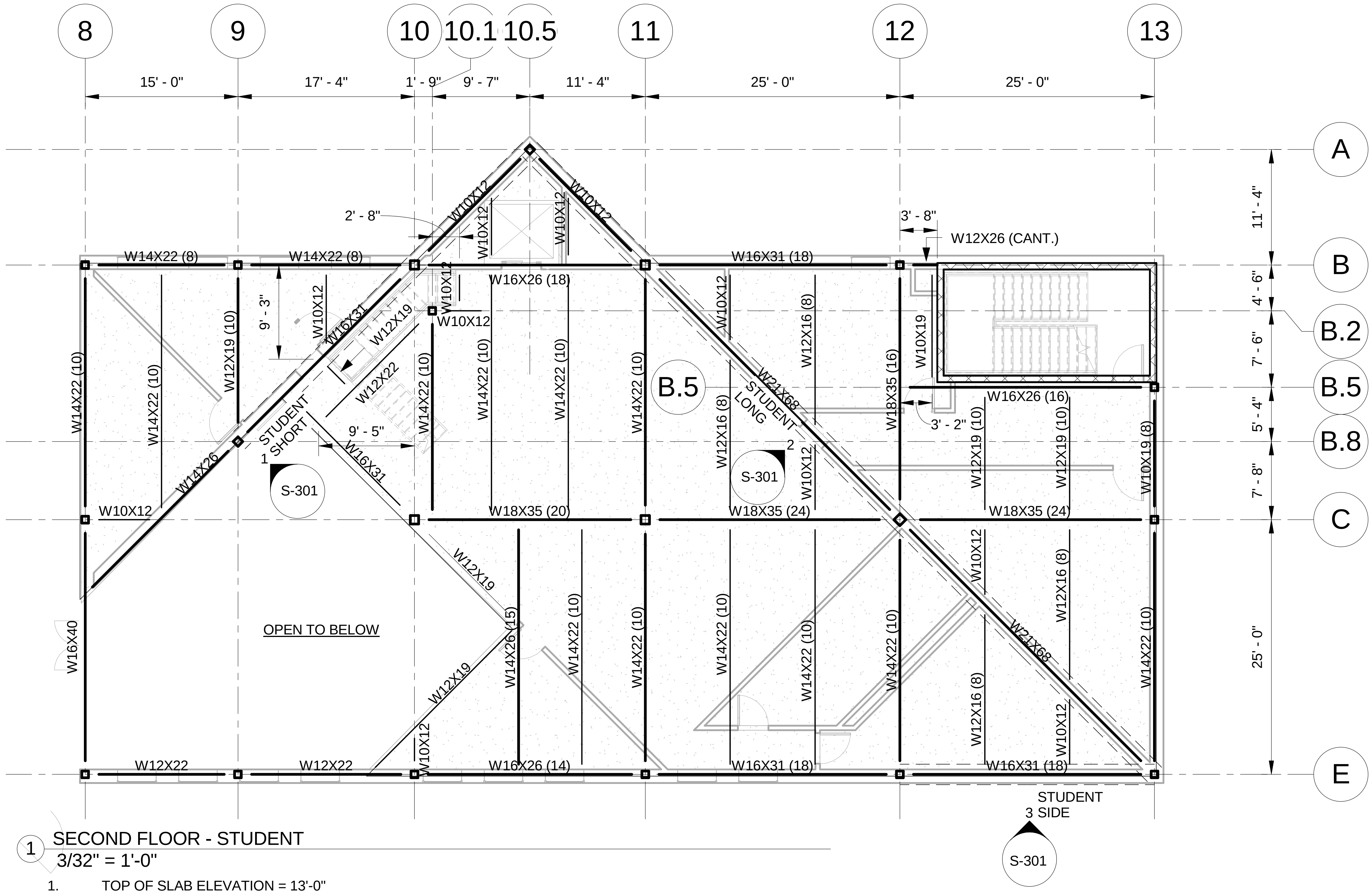


No.	Description	Date

FIRST FLOOR - ADMIN

Project number	Project Number	S-110
Date	3/3/16	
Drawn by	JDS	
Checked by	Checker	Scale 3/32" = 1'-0"

3/24/2016 1:00:38 AM



1 SECOND FLOOR - STUDENT
3/32" = 1'-0"

1. TOP OF SLAB ELEVATION = 13'-0"
2. TOP OF STEEL ELEVATION = (-0'-6 1/4") FROM TOP OF SLAB
3. FLOOR CONSTRUCTION: 3 1/4" LIGHTWEIGHT CONCRETE ON 3" 20ga. COMPOSITE METAL FLOOR DECK REINFORCED WITH 6x6-W2.1xW2.1 W.W.F.
4. (##) - INDICATES THE NUMBER OF 3/4" DIA. x 5" LONG SHEAR STUDS UNIFORMLY SPACED ALONG THE BEAM

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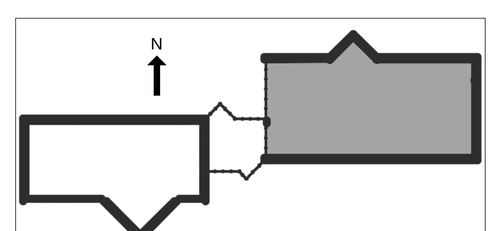

No.	Description	Date

SECOND FLOOR - STUDENT

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Date	3/3/16	
Drawn by	JDS	
Checked by	Checker	Scale 3/32" = 1'-0"

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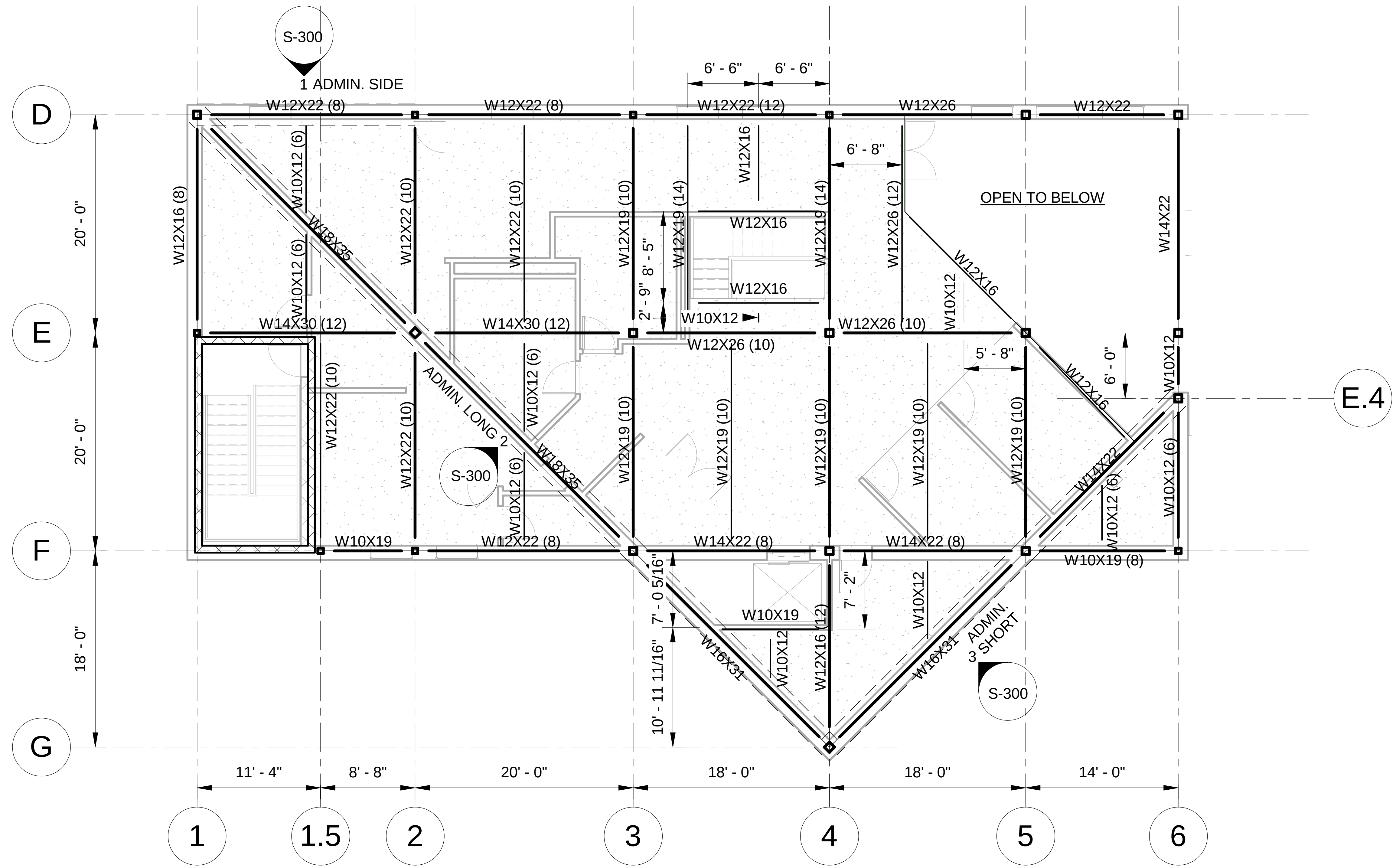

1 SECOND FLOOR - ADMINISTRATION
3/32" = 1'-0"

1. TOP OF SLAB ELEVATION = 13'-0"
2. TOP OF STEEL ELEVATION = (-0'-6 1/2") FROM TOP OF SLAB
3. FLOOR CONSTRUCTION: 3 1/2" NORMAL WEIGHT CONCRETE ON 3" 20ga. COMPOSITE METAL FLOOR DECK REINFORCED WITH 6x6-W2.1xW2.1 W.W.F.
4. (##) - INDICATES THE NUMBER OF 3/4" DIA. x 5" LONG SHEAR STUDS UNIFORMLY SPACED ALONG THE BEAM

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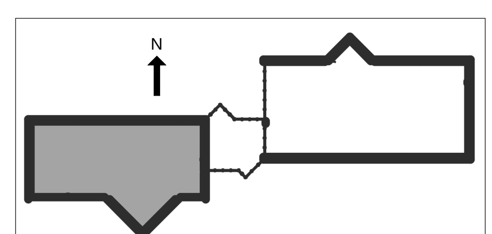
GATEWAY CAMPUS CENTER

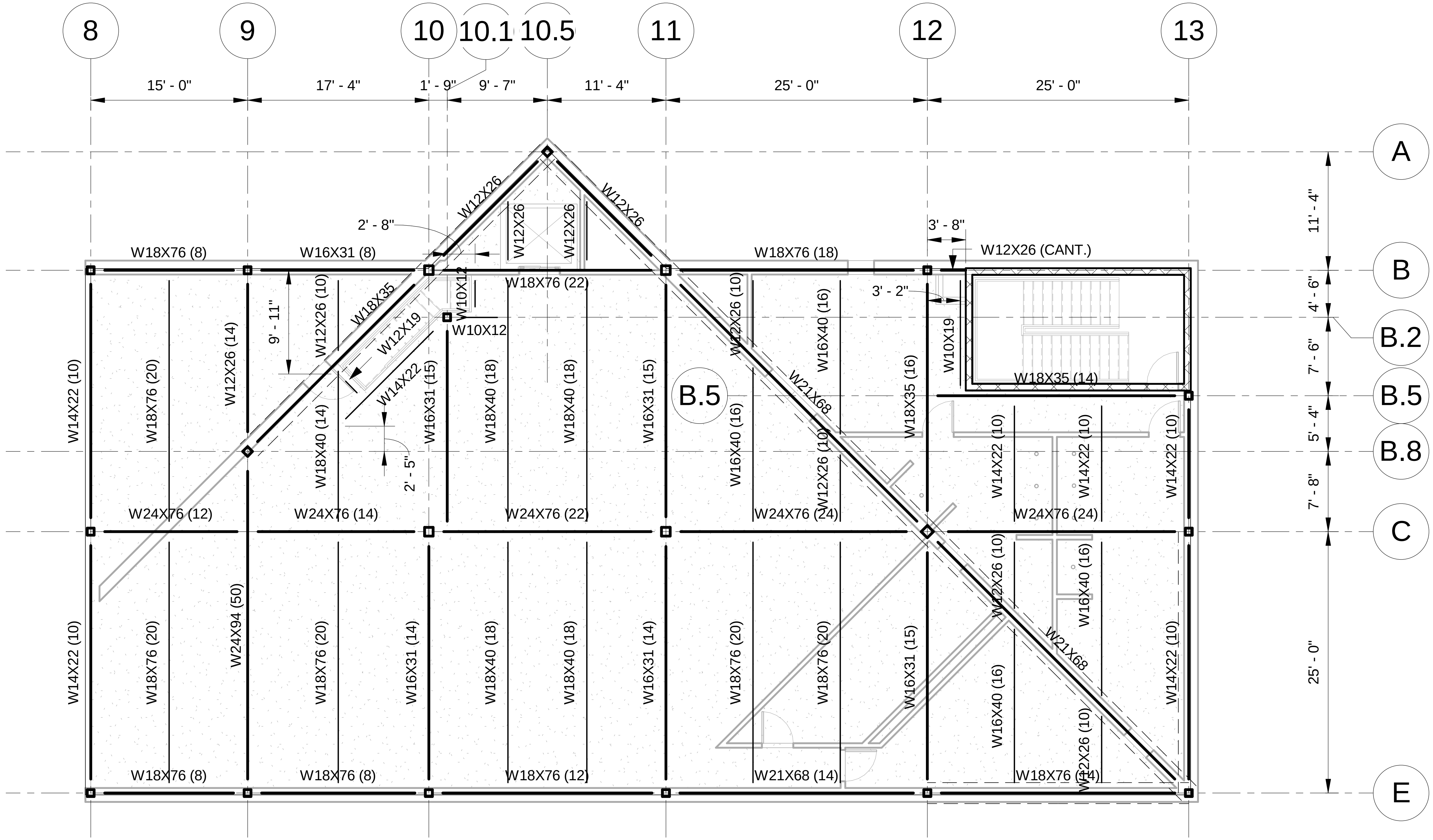


No.	Description	Date

SECOND FLOOR - ADMIN

Project number	Project Number	S-112
Date	3/3/16	
Drawn by	JDS	
Checked by	Checker	Scale 3/32" = 1'-0"

3/24/2016 1:00:40 AM



1 THIRD FLOOR - STUDENT

3/32" = 1'-0"

1. TOP OF SLAB ELEVATION = 26'-0"
2. TOP OF STEEL ELEVATION = (-0'-6 1/4") FROM TOP OF SLAB
3. FLOOR CONSTRUCTION: 3 1/4" LIGHTWEIGHT CONCRETE ON 3" 20ga. COMPOSITE METAL FLOOR DECK REINFORCED WITH 6x6-W2.1xW2.1 W.W.F.
4. (##) - INDICATES THE NUMBER OF 3/4" DIA. x 5" LONG SHEAR STUDS UNIFORMLY SPACED ALONG THE BEAM

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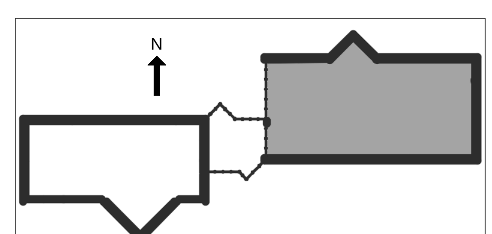
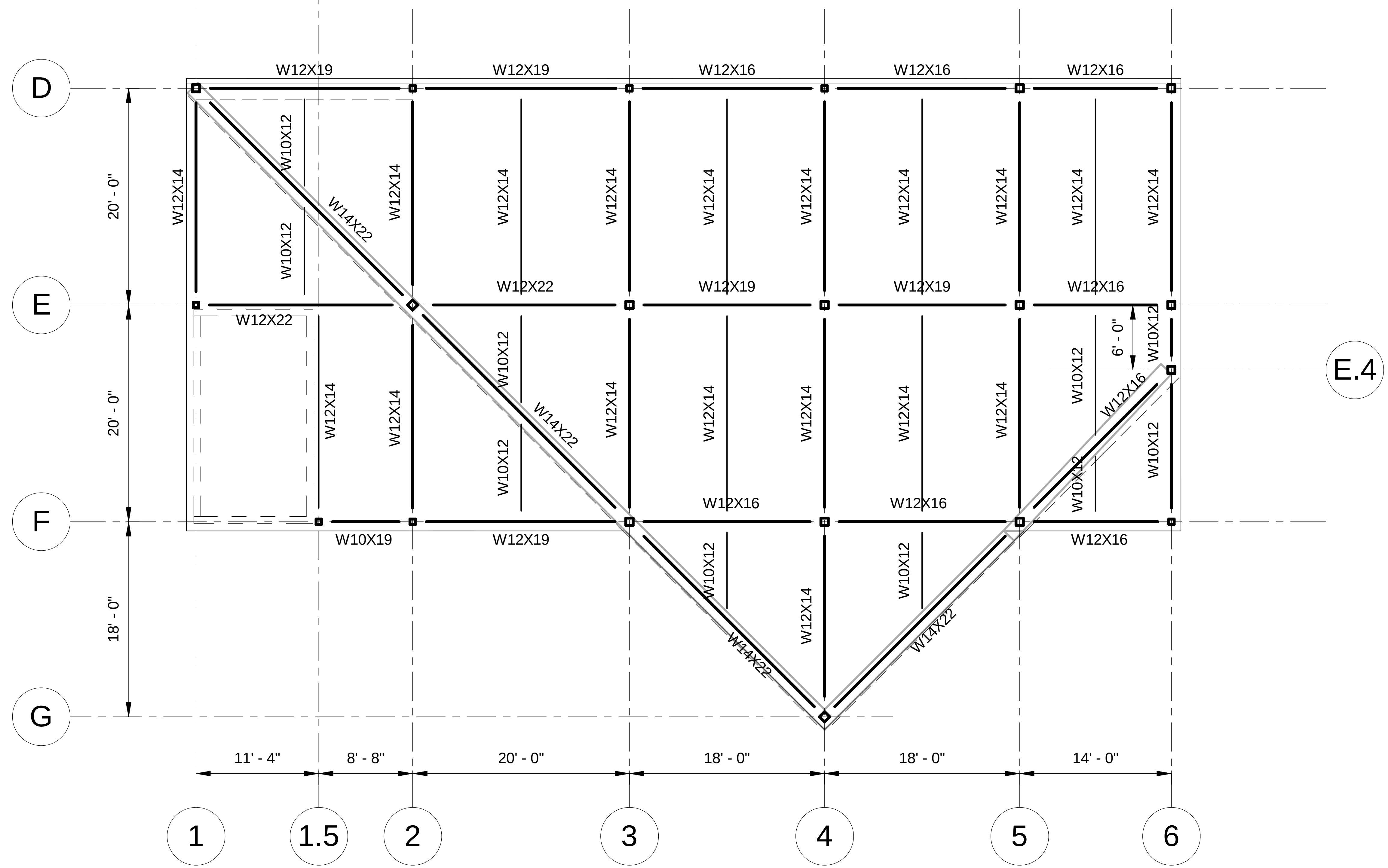


No.	Description	Date

THIRD FLOOR - STUDENT

Project number	Project Number	S-113
Date	3/3/16	
Drawn by	JDS	
Checked by	Checker	Scale 3/32" = 1'-0"

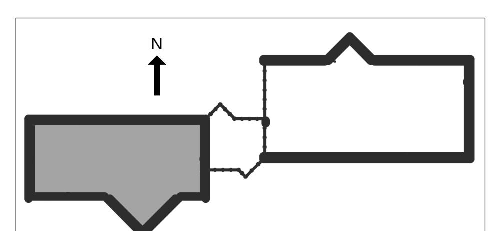
3/24/2016 1:00:40 AM



1 ROOF - ADMINISTRATION
3/32" = 1'-0"

1. TOP OF DECKING ELEVATION = 26'-0"
2. TOP OF STEEL ELEVATION = (-0'-3") FROM TOP OF SLAB
3. FLOOR CONSTRUCTION: 3" DEEP 20ga. METAL ROOF DECK

GATEWAY CAMPUS CENTER

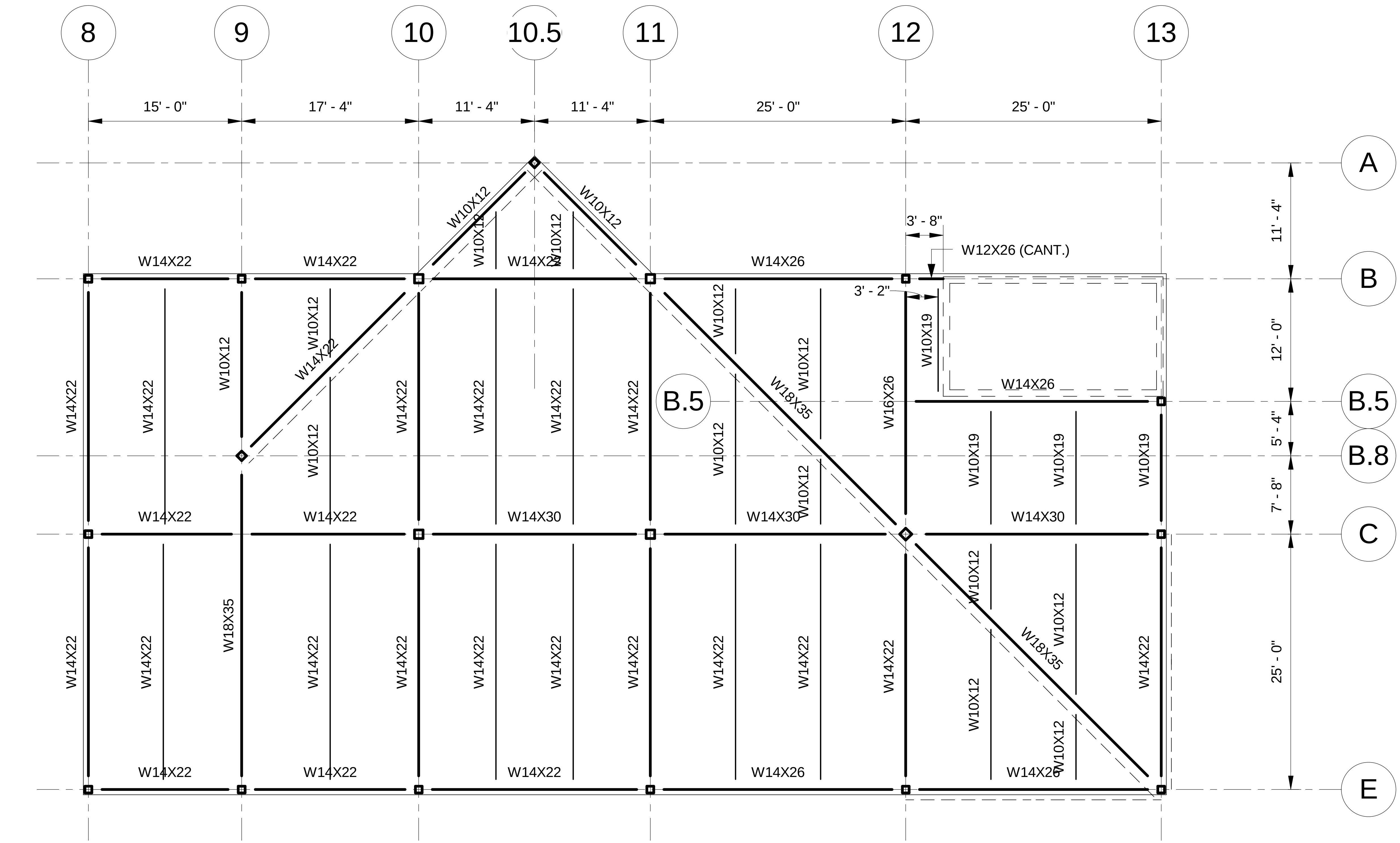


No.	Description	Date

ROOF - ADMINISTRATION

Project number	Project Number	S-114
Date	3/3/16	
Drawn by	JDS	
Checked by	Checker	Scale 3/32" = 1'-0"

3/24/2016 1:00:41 AM



1 ROOF - STUDENT
3/32" = 1'-0"

1. TOP OF DECKING ELEVATION = 39'-0"
2. TOP OF STEEL ELEVATION = (-0'-3") FROM TOP OF SLAB
3. FLOOR CONSTRUCTION: 3" DEEP 20ga. METAL ROOF DECK

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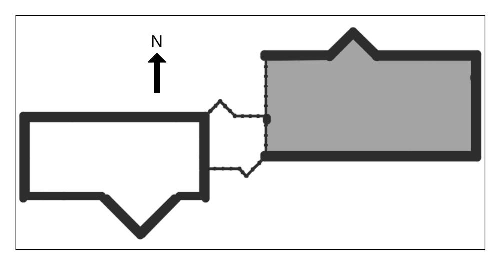

No.	Description	Date

ROOF - STUDENT

Project number	Project Number	S-115
Date	3/3/16	
Drawn by	JDS	
Checked by	Checker	Scale 3/32" = 1'-0"

3/24/2016 1:00:41 AM

Third Floor/Roof 1	26' - 0"
Second Floor	13' - 0"
First Floor	0' - 0"
Basement	-13' - 0"

Column Locations	D-1	D-2	D-3	D-4	D-5	D-6	E-1	E-2	E-3	E-4	E-5	E-6	E.4-6	F-1.5	F-2	F-3	F-4	F-5	F-6	G-4
Column	HSS8X8X5/16	HSS6X6X5/16	HSS6X6X5/16	HSS6X6X5/16	HSS8X8X5/16	HSS8X8X5/16	HSS6X6X5/16	HSS8X8X5/16	HSS8X8X5/16	HSS8X8X5/16	HSS8X8X5/16	HSS8X8X5/16	HSS8X8X5/16	HSS6X6X5/16	HSS6X6X5/16	HSS8X8X5/16	HSS8X8X5/16	HSS8X8X5/16	HSS6X6X5/16	HSS8X8X5/16

Column Schedule - Administration
1/16" = 1'-0"

Roof 2	39' - 0"
Third Floor/Roof 1	26' - 0"
Second Floor	13' - 0"
First Floor	0' - 0"

Column Locations	A-10.5	B-8	B-9	B-10	B-11	B-12	B.2-10.1	B.5-13	B.8-9	C-8	C-10	C-11	C-12	C-13	E-8	E-9	E-10	E-11	E-12	E-13
Column	HSS8X8X5/16	HSS8X8X5/16	HSS8X8X5/16	HSS10X10X5/16	HSS10X10X5/16	HSS8X8X5/16	HSS8X8X5/16	HSS8X8X5/16	HSS8X8X5/16	HSS8X8X5/16	HSS10X10X5/16	HSS10X10X5/16	HSS10X10X3/8	HSS8X8X5/16	HSS8X8X5/16	HSS8X8X5/16	HSS8X8X5/16	HSS8X8X5/16	HSS8X8X5/16	HSS8X8X5/16

Column Schedule - Student
1/16" = 1'-0"

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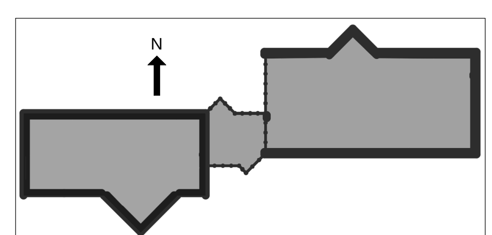
GATEWAY CAMPUS CENTER



No.	Description	Date

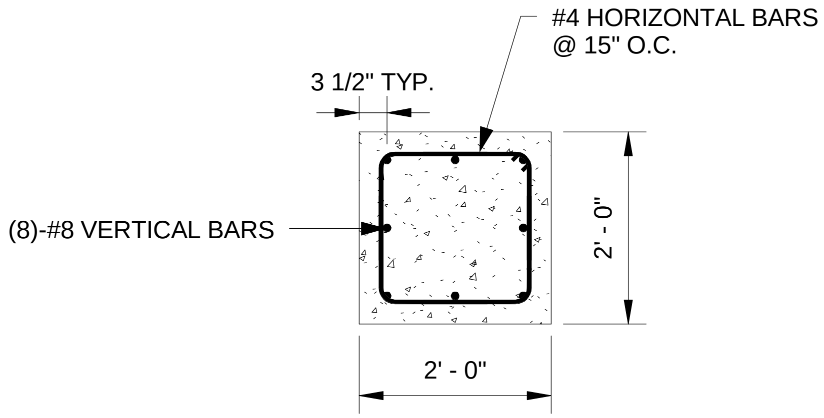
COLUMN SCHEDULE

Project number	Project Number
Date	3/3/16
Drawn by	JDS
Checked by	Checker

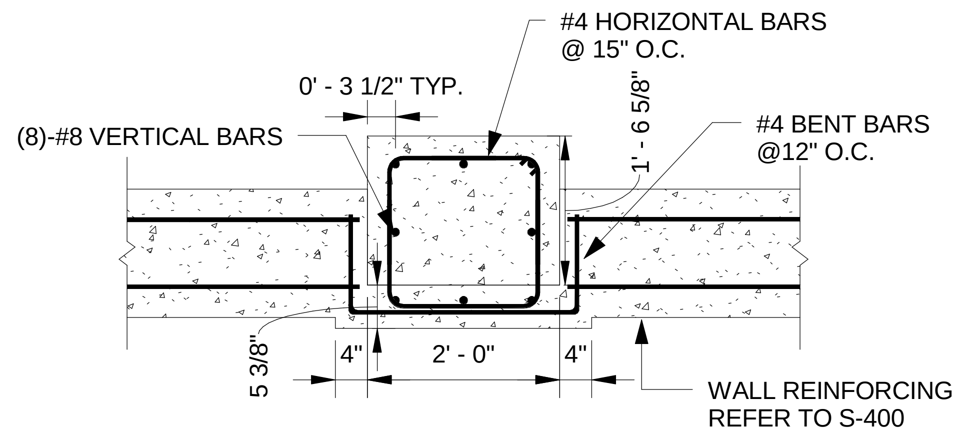
S-200

Scale 1/16" = 1'-0"

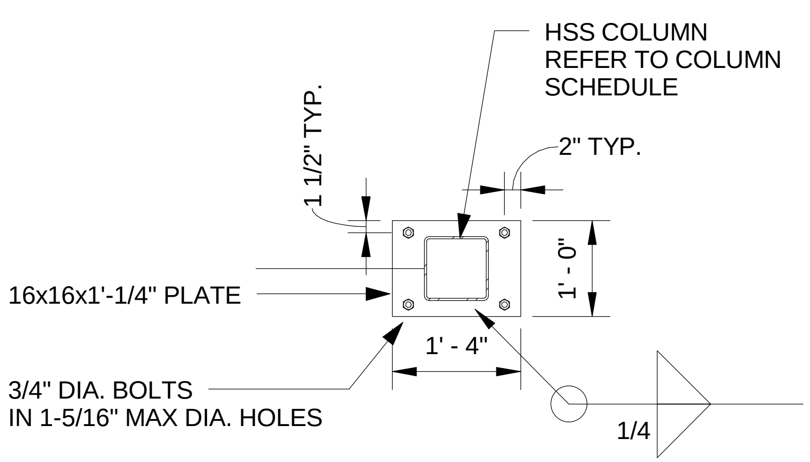
3/24/2016 1:00:42 AM



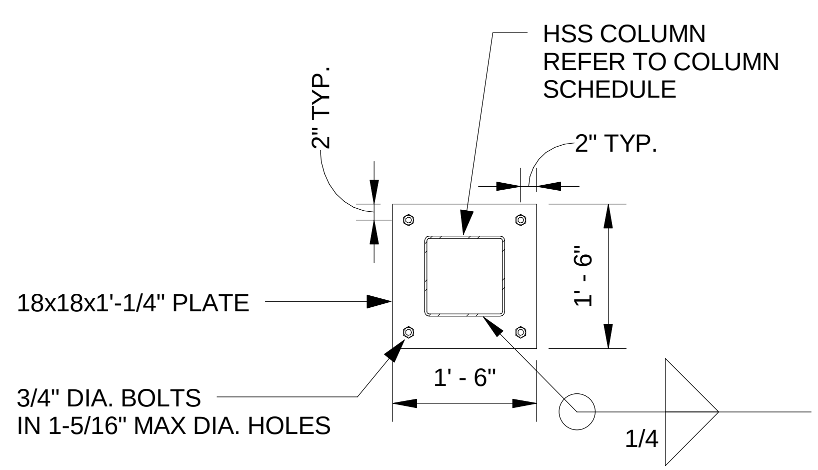
1 P-1
1/2" = 1'-0"



2 P-1 BETWEEN WALLS
1/2" = 1'-0"



3 BP-1
1/2" = 1'-0"



4 BP-2
1/2" = 1'-0"

COLUMN	PIER	BASE PLATE
A-10.5	P-1	BP-1
B-8	P-1	BP-1
B-9	P-1	BP-1
B-10	P-1	BP-1
B-11	P-1	BP-1
B-12	P-1	BP-1
B.2-10.1	P-1	BP-1
B.5-13	P-1	BP-1
B.8-9	N/A	BP-2
C-8	P-1	BP-1
C-10	N/A	BP-2
C-11	N/A	BP-2
C-12	N/A	BP-2
C-13	P-1	BP-1
D-1	P-1	BP-1
D-2	P-1	BP-1
D-3	P-1	BP-1
D-4	P-1	BP-1
D-5	P-1	BP-1
D-6	P-1	BP-1

COLUMN	PIER	BASE PLATE
E-1	P-1	BP-1
E-2	N/A	BP-2
E-3	N/A	BP-2
E-4	N/A	BP-2
E-5	N/A	BP-2
E-6	P-1	BP-1
E-8	P-1	BP-1
E-9	P-1	BP-1
E-10	P-1	BP-1
E-11	P-1	BP-1
E-12	P-1	BP-1
E-13	P-1	BP-1
E.4-6	P-1	BP-1
F-1.5	P-1	BP-1
F-2	P-1	BP-1
F-3	P-1	BP-1
F-4	N/A	BP-2
F-5	P-1	BP-1
F-6	P-1	BP-1
G-4	P-1	BP-1

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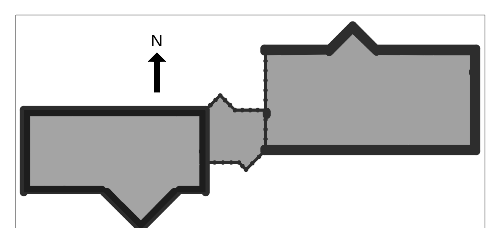
GATEWAY CAMPUS CENTER

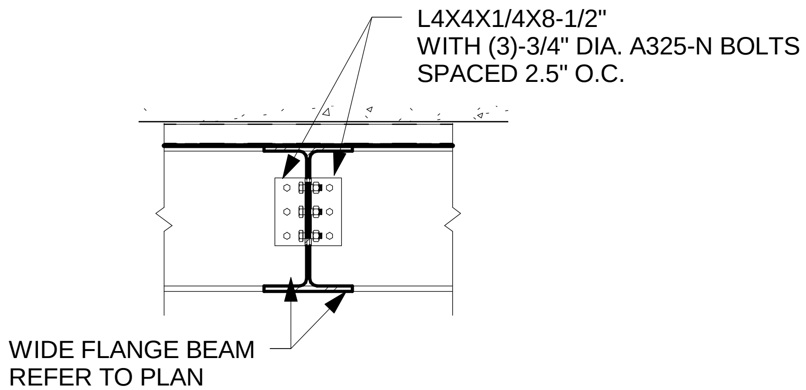


No.	Description	Date

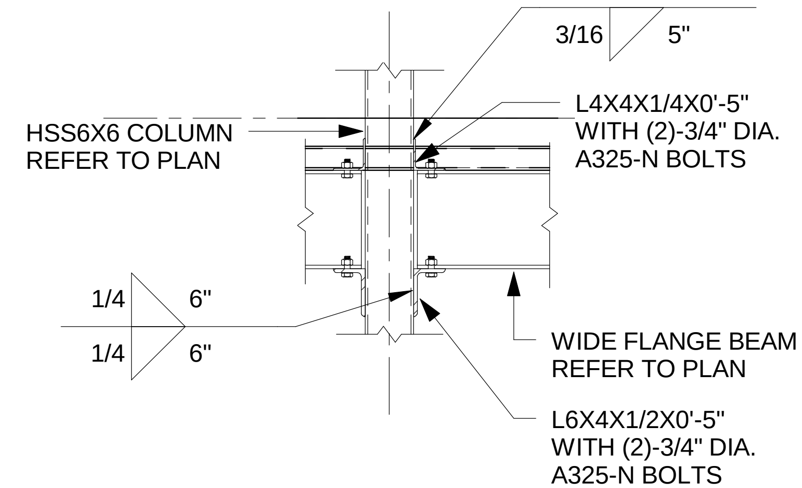
TYPICAL DETAILS

Project number	Project Number	S-201
Date	3/3/16	
Drawn by	JDS	
Checked by	Checker	Scale 1/2" = 1'-0"

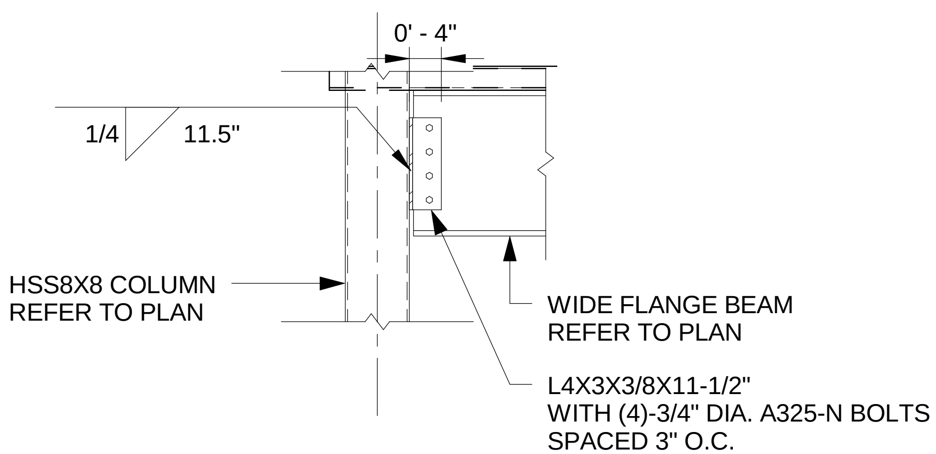
3/24/2016 1:00:43 AM



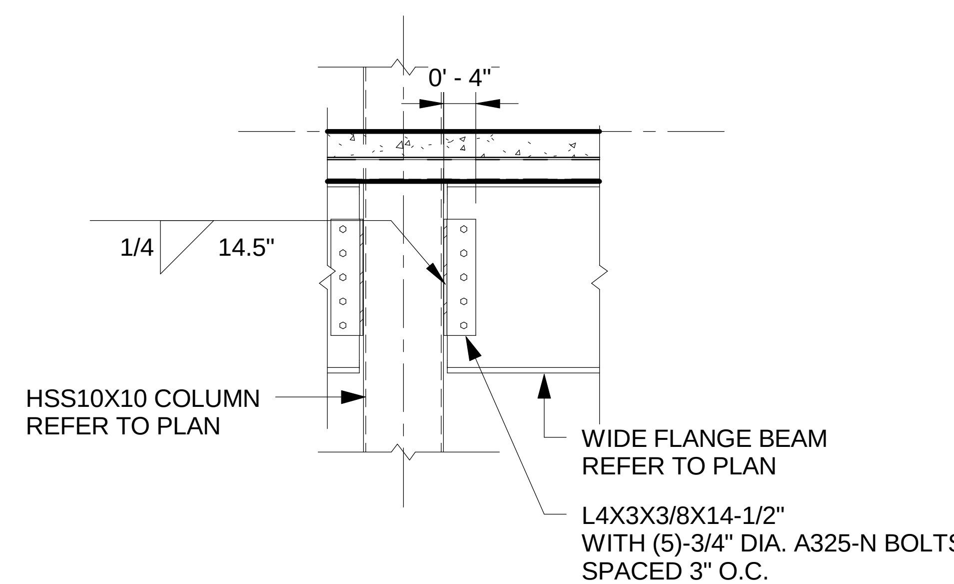
1 TYPICAL BEAM TO GIRDER CONNECTION
1/2" = 1'-0"



2 TYPICAL CONNECTION TO HSS6X6 COLUMN
1/2" = 1'-0"

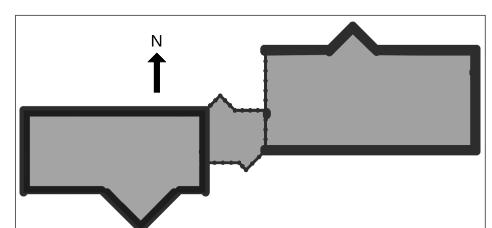


3 TYPICAL CONNECTION TO HSS8X8 COLUMN
1/2" = 1'-0"



4 TYPICAL CONNECTION TO HSS10X10 COLUMN
1/2" = 1'-0"

GATEWAY CAMPUS CENTER

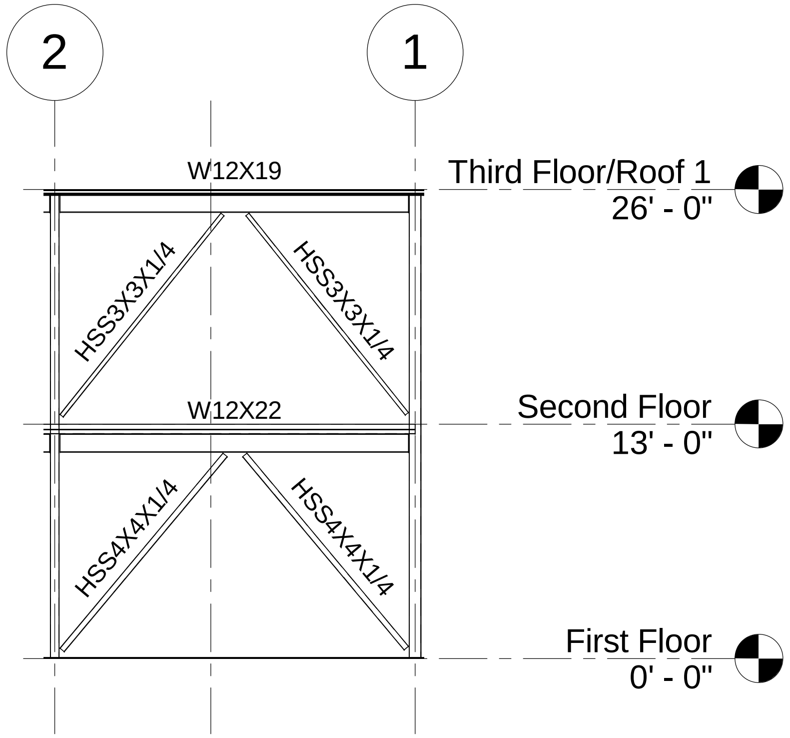


No.	Description	Date

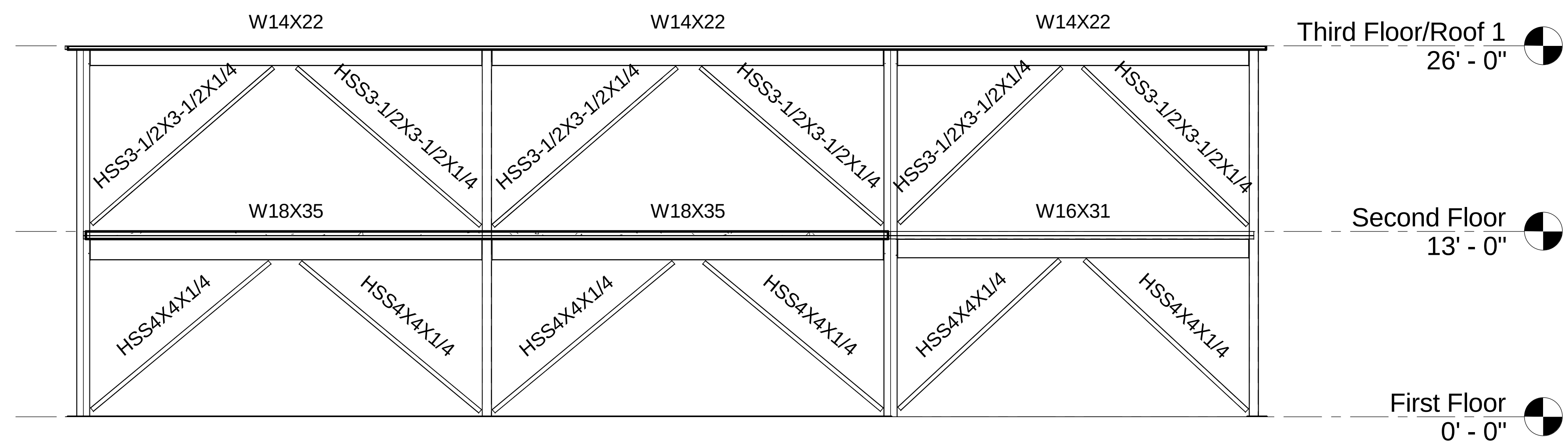
TYPICAL DETAILS

Project number	Project Number	S-202
Date	3/3/16	
Drawn by	JDS	
Checked by	Checker	Scale 1/2" = 1'-0"

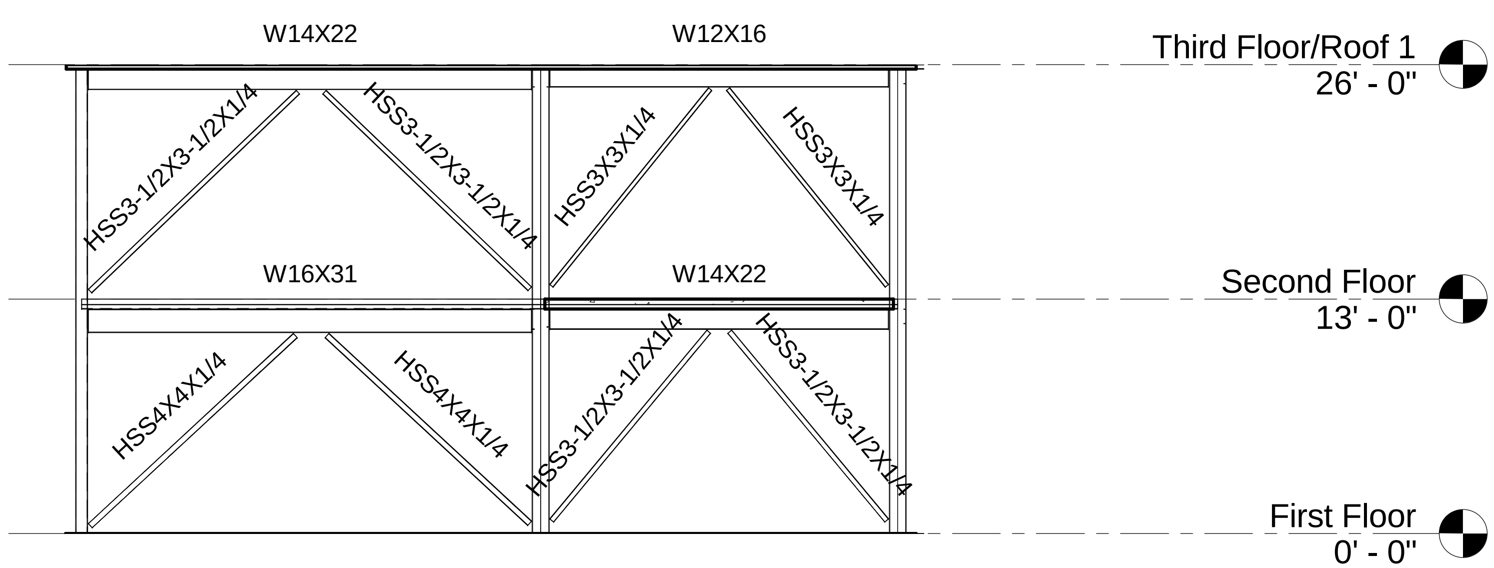
3/24/2016 1:00:44 AM



1 ADMIN. SIDE
3/32" = 1'-0"



2 ADMIN. LONG
3/32" = 1'-0"



3 ADMIN. SHORT
3/32" = 1'-0"

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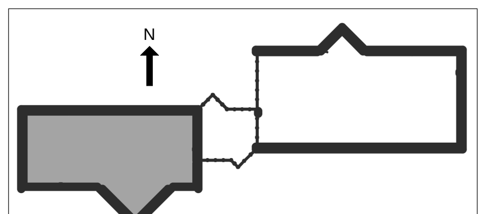
GATEWAY CAMPUS CENTER

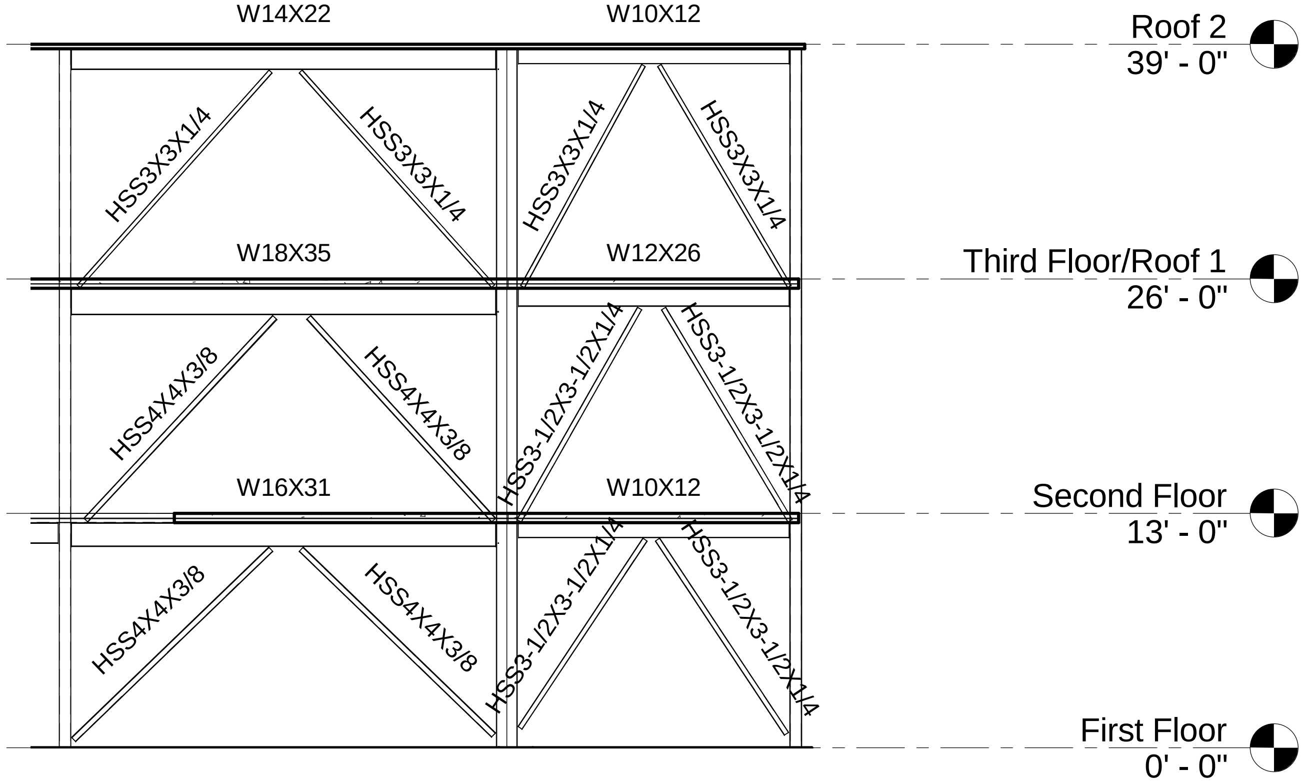


No.	Description	Date

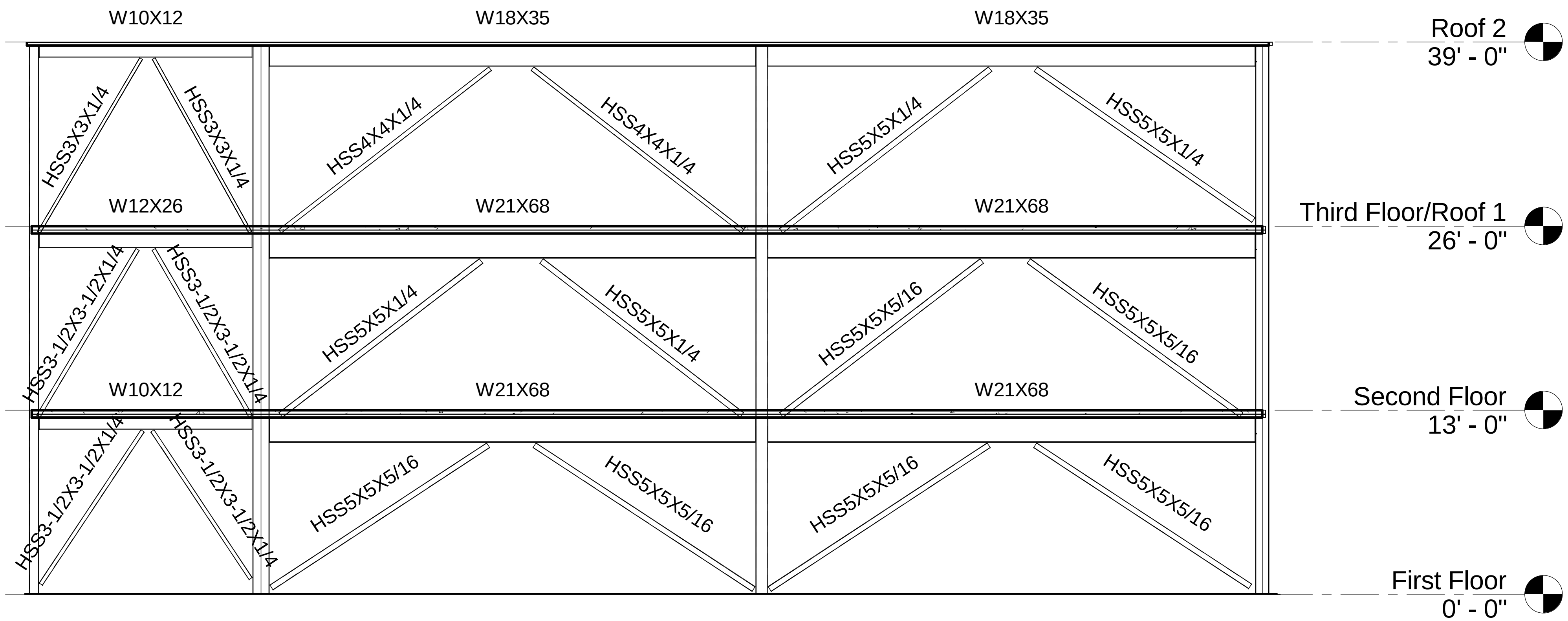
BRACE WALL - ADMIN

Project number	Project Number	S-300
Date	3/3/16	
Drawn by	JDS	
Checked by	Checker	Scale 3/32" = 1'-0"

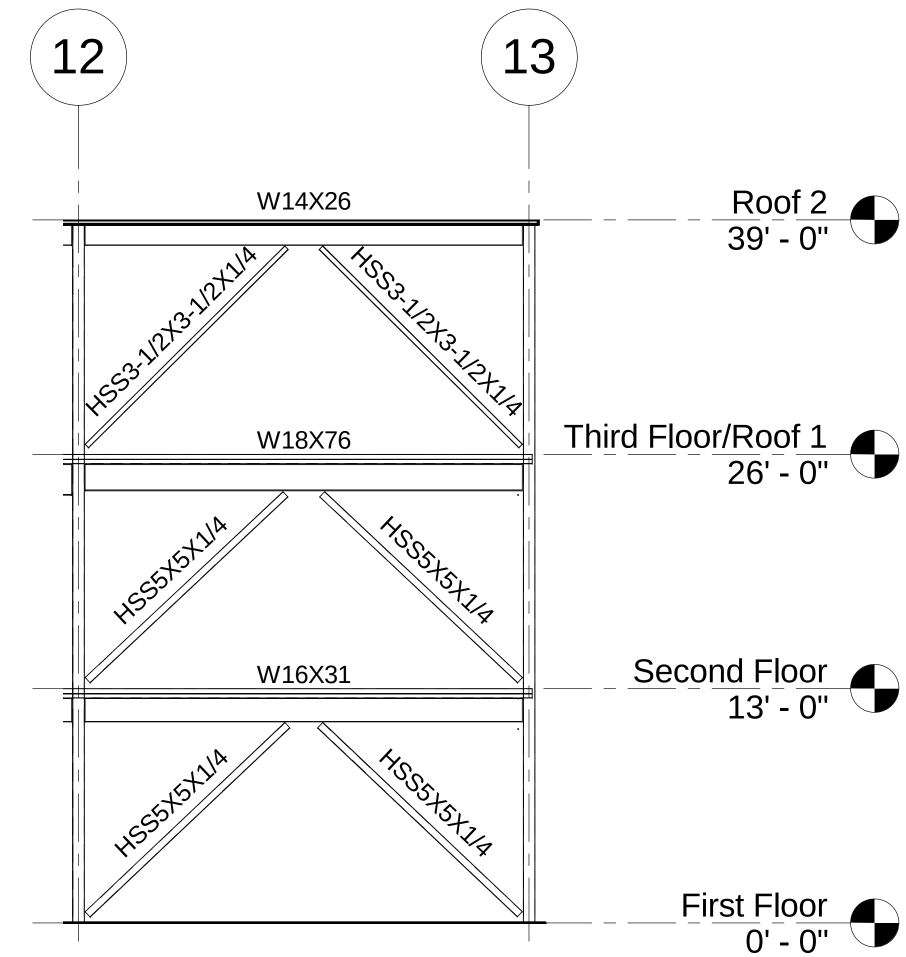
3/24/2016 1:00:44 AM



1 STUDENT SHORT
3/32" = 1'-0"



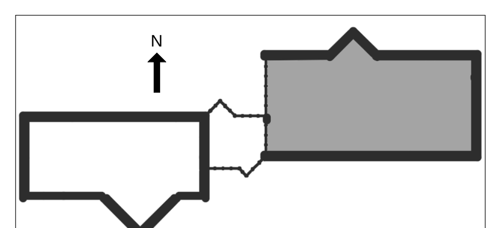
2 STUDENT LONG
3/32" = 1'-0"



3 STUDENT SIDE
3/32" = 1'-0"

WPI

GATEWAY CAMPUS CENTER



No.	Description	Date

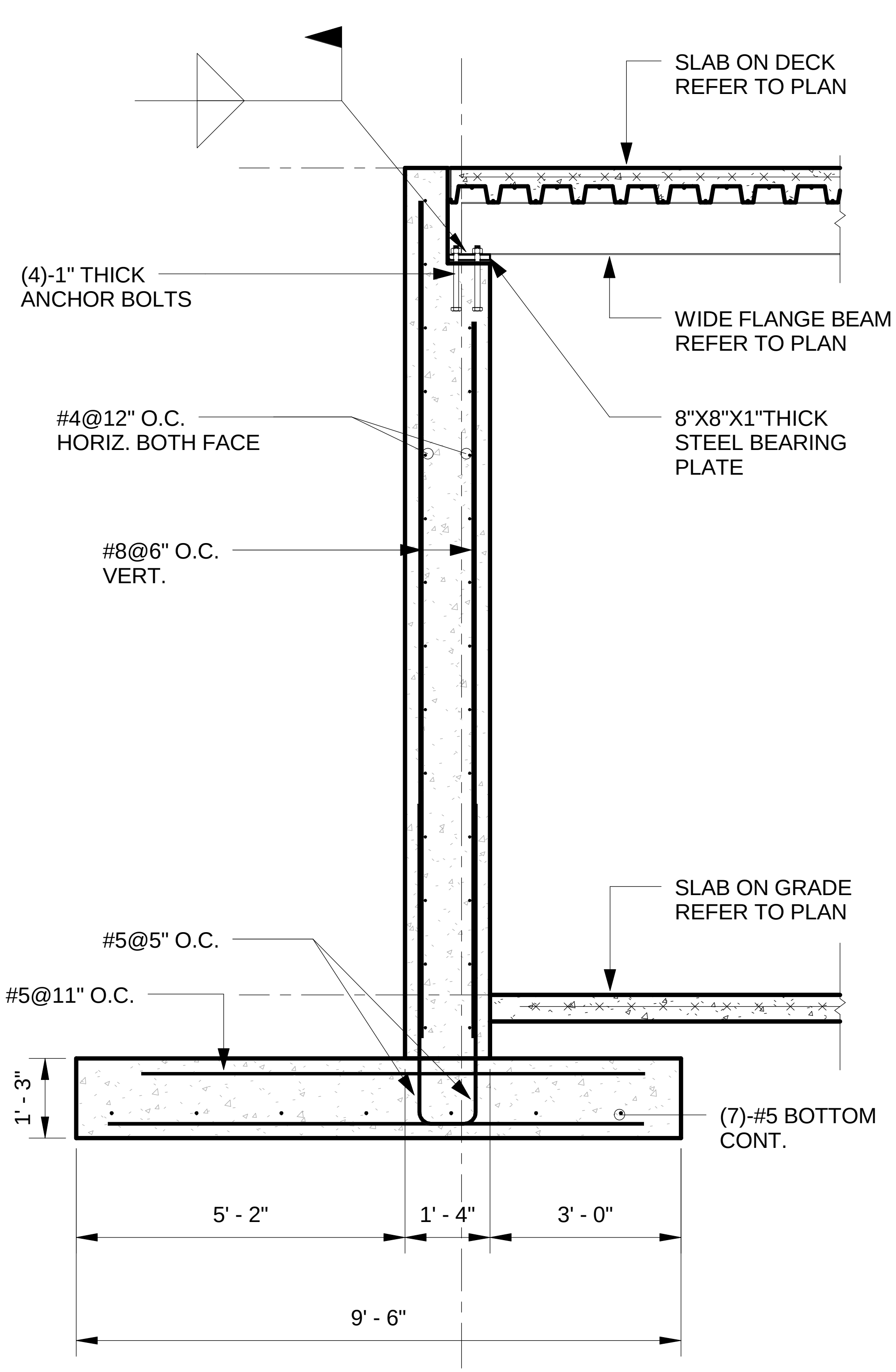
BRACE WALL - STUDENT

Project number	Project Number
Date	3/3/16
Drawn by	JDS
Checked by	Checker

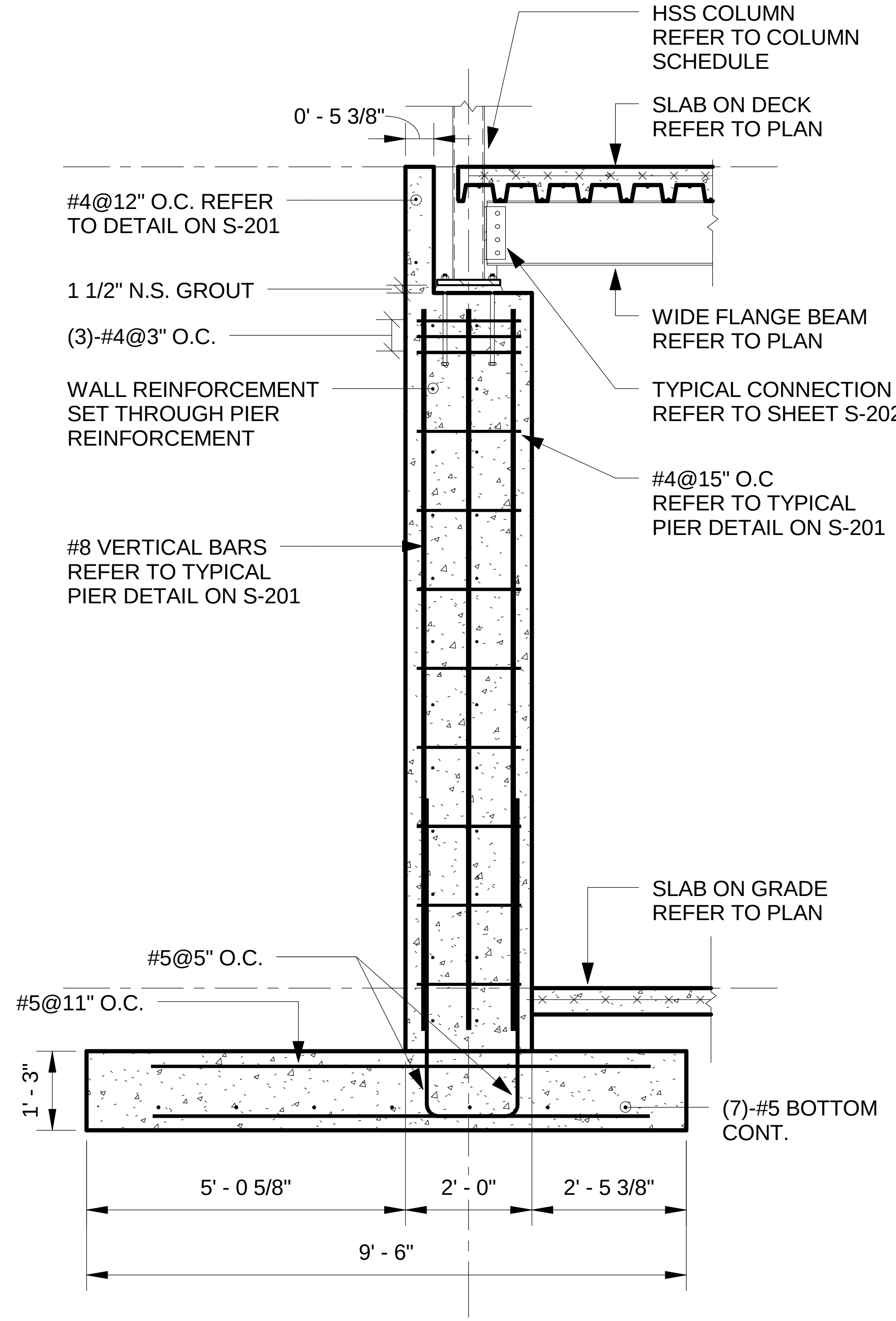
S-301

Scale 3/32" = 1'-0"

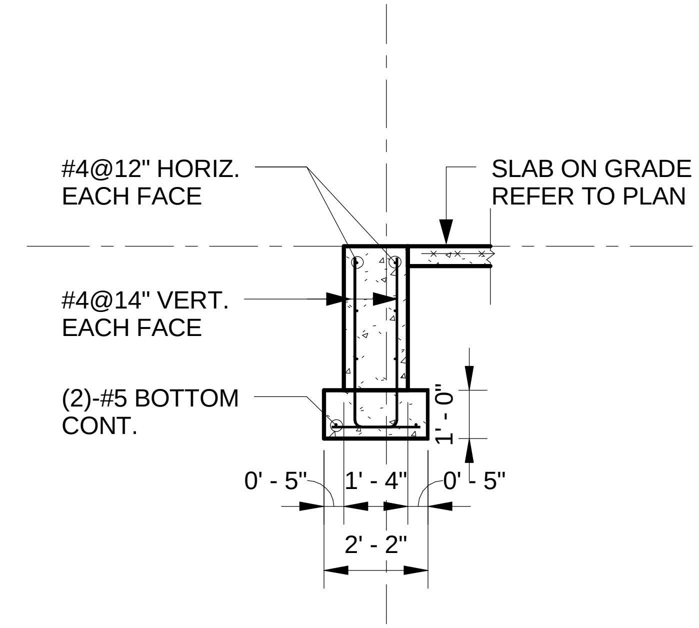
3/24/2016 1:00:45 AM



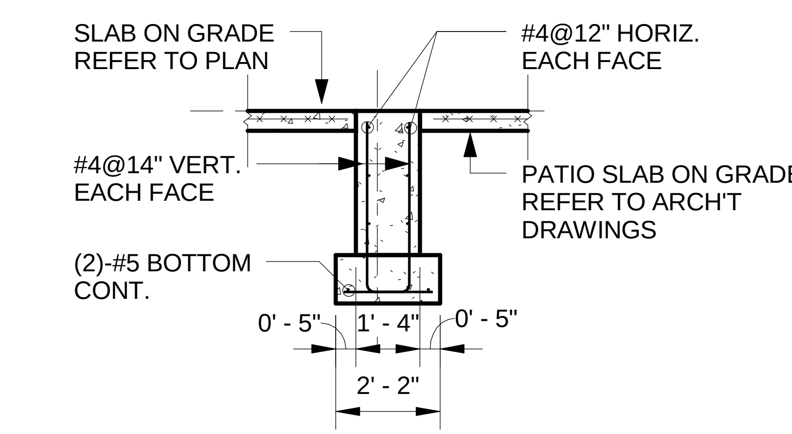
1 SECTION
3/8" = 1'-0"



2 SECTION
3/8" = 1'-0"



3 SECTION
1/4" = 1'-0"



4 SECTION
1/4" = 1'-0"

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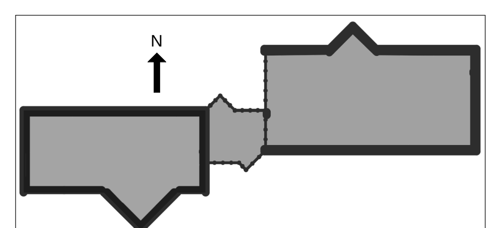
GATEWAY CAMPUS CENTER

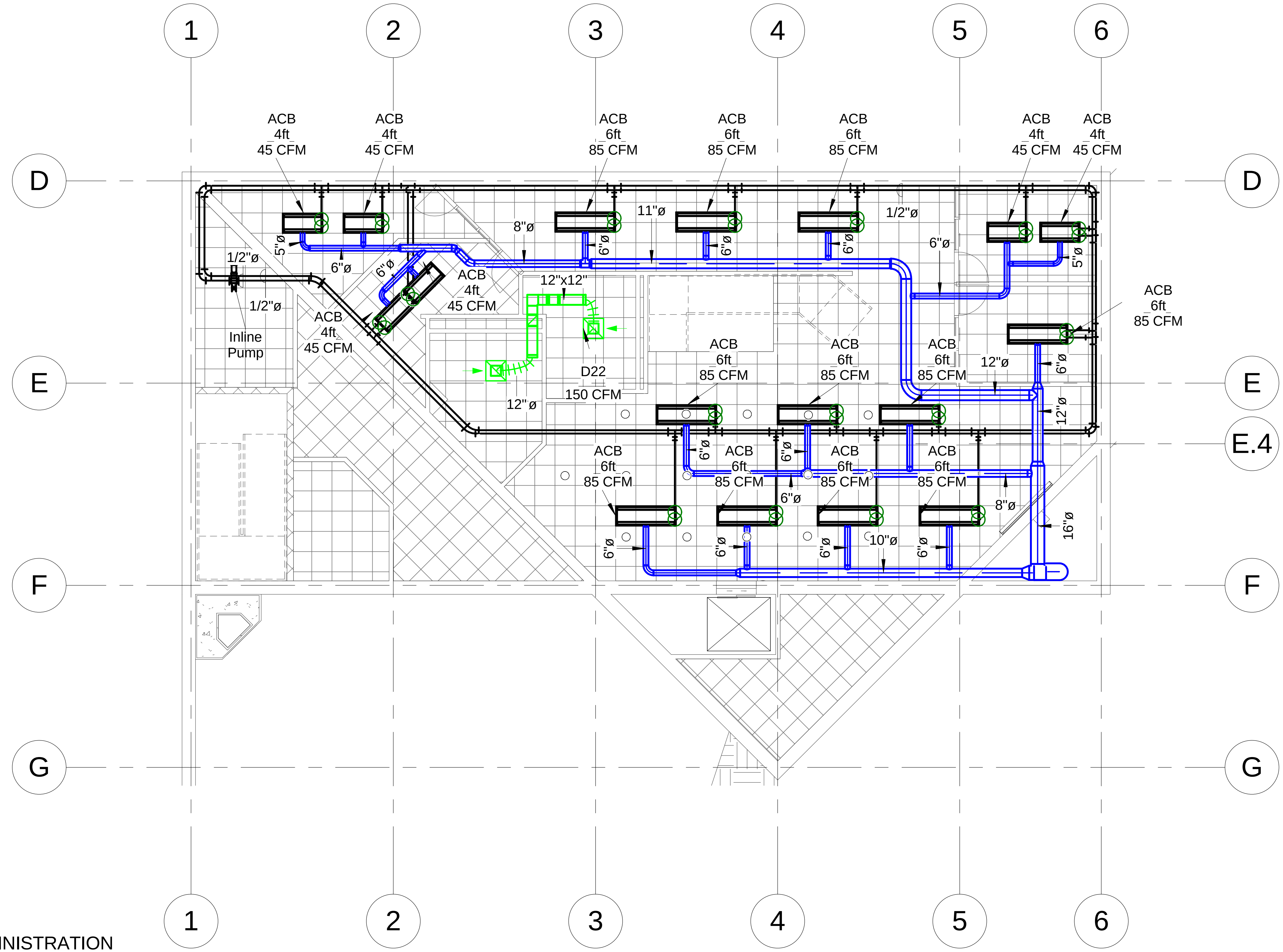


No.	Description	Date

FOUNDATION SECTIONS

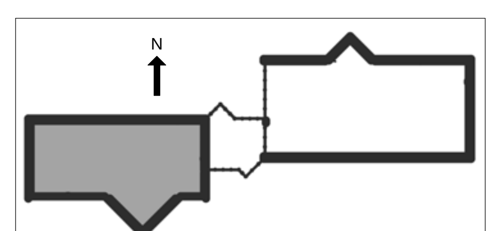
Project number	Project Number	S-400
Date	3/3/16	
Drawn by	JDS	
Checked by	Checker	Scale As indicated

3/24/2016 1:00:46 AM



1 BASEMENT - ADMINISTRATION
3/32" = 1'-0"

GATEWAY CAMPUS CENTER

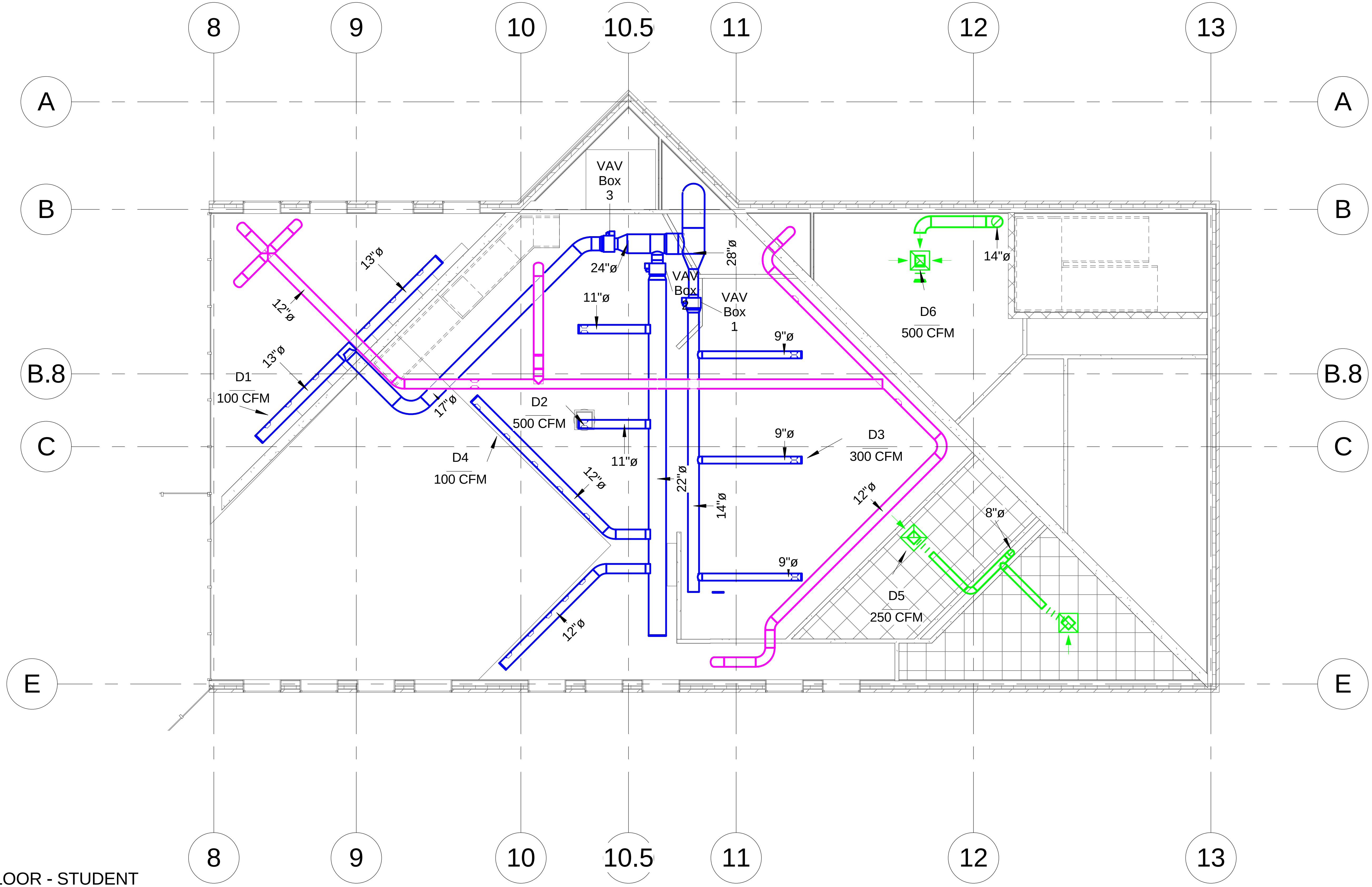


No.	Description	Date

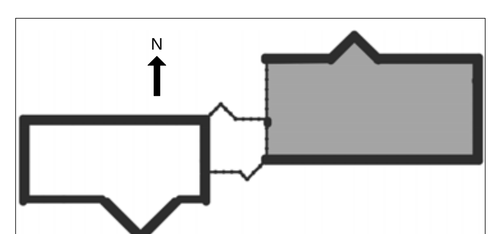
BASEMENT - ADMIN

Project number	Project Number	M-101
Date	Issue Date	
Drawn by	Author	
Checked by	Checker	Scale 3/32" = 1'-0"

3/24/2016 2:34:25 AM



1 FIRST FLOOR - STUDENT
3/32" = 1'-0"



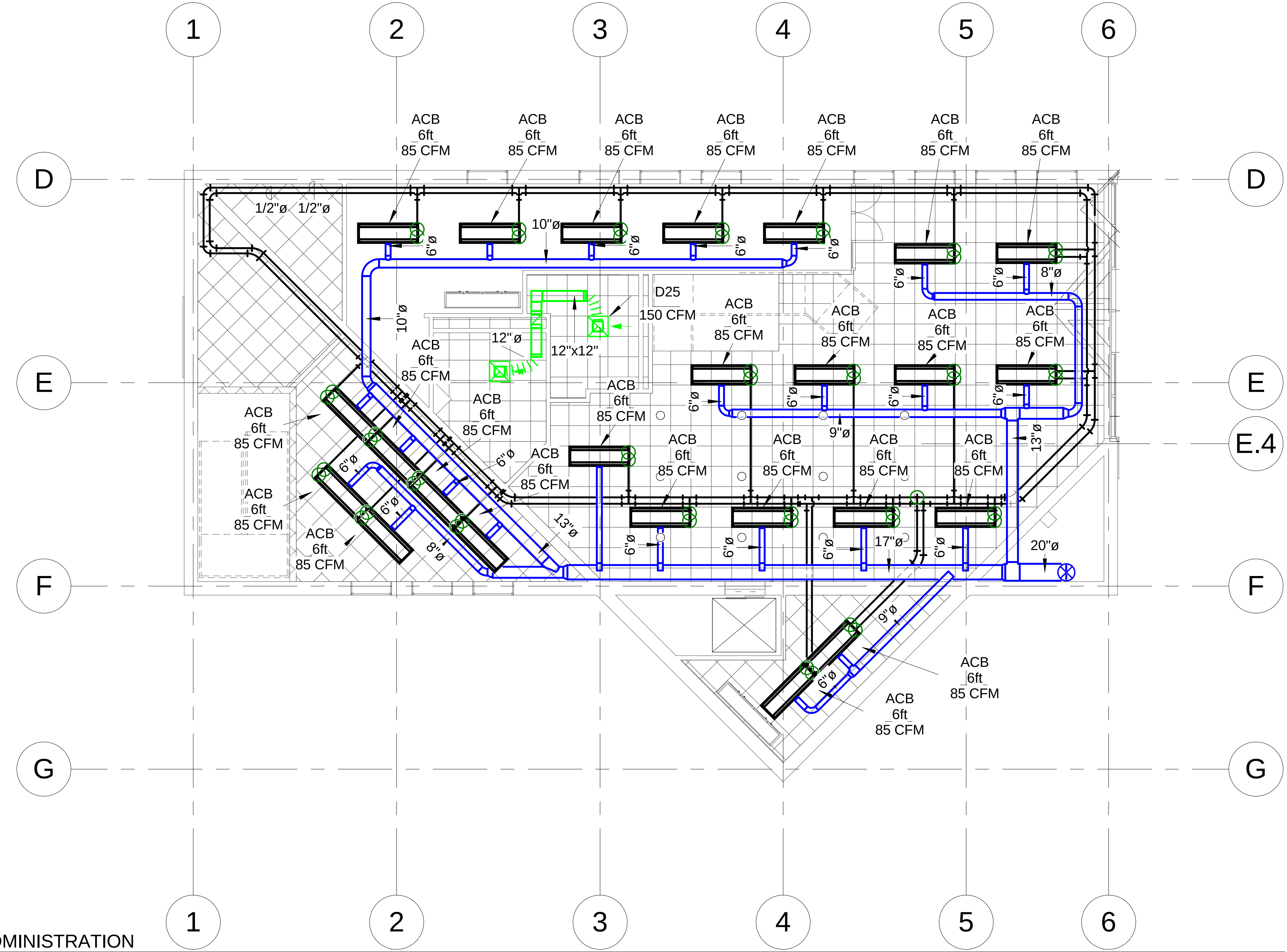
GATEWAY CAMPUS CENTER

No.	Description	Date

FIRST FLOOR - STUDENT

Project number	Project Number	M-102
Date	Issue Date	
Drawn by	Author	
Checked by	Checker	Scale 3/32" = 1'-0"

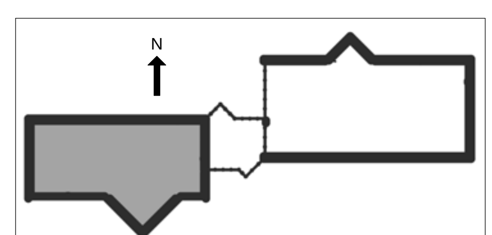
3/24/2016 2:34:26 AM



1 FIRST FLOOR - ADMINISTRATION
3/32" = 1'-0"

WPI

GATEWAY CAMPUS CENTER

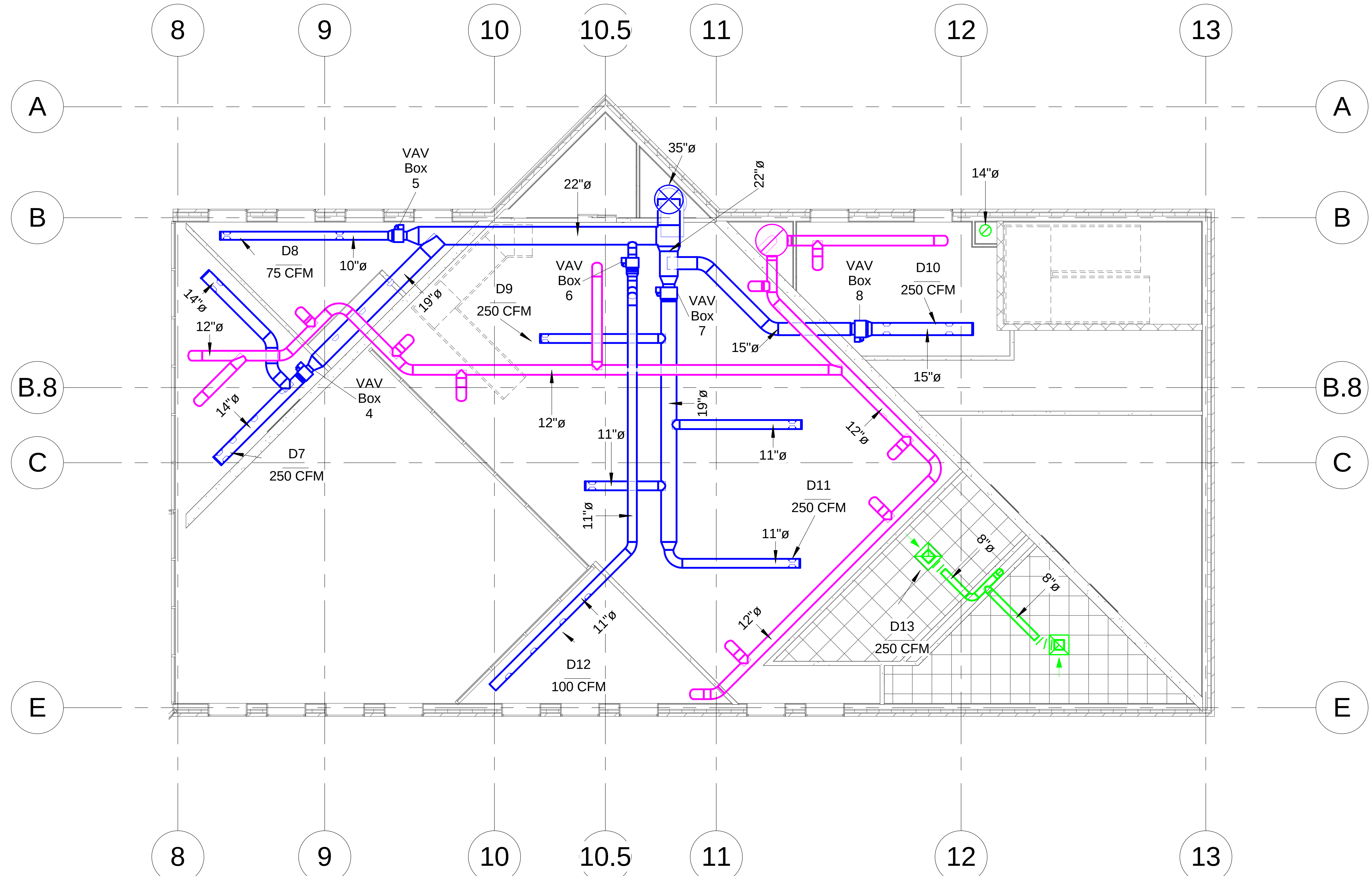


No.	Description	Date

FIRST FLOOR - ADMIN

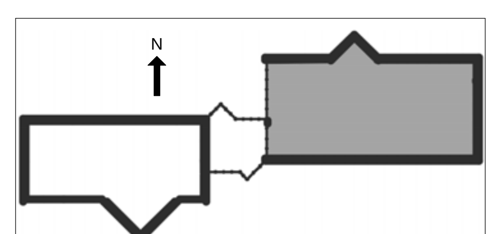
Project number	Project Number	M-103
Date	Issue Date	
Drawn by	Author	
Checked by	Checker	Scale 3/32" = 1'-0"

3/24/2016 2:34:29 AM



1 SECOND FLOOR - STUDENT
3/32" = 1'-0"

GATEWAY CAMPUS CENTER

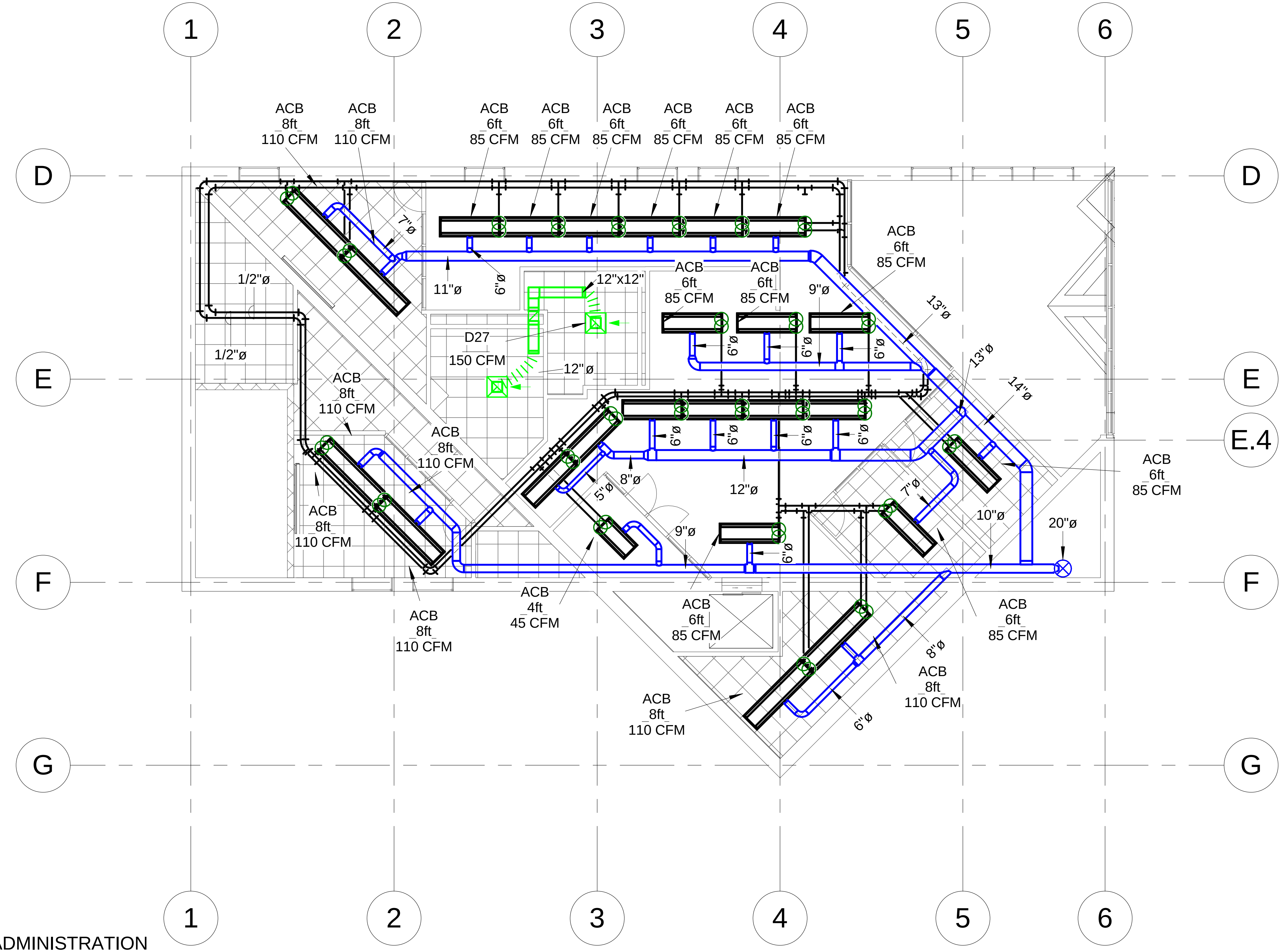


No.	Description	Date

SECOND FLOOR - STUDENT

Project number	Project Number	M-104
Date	Issue Date	
Drawn by	Author	
Checked by	Checker	Scale 3/32" = 1'-0"

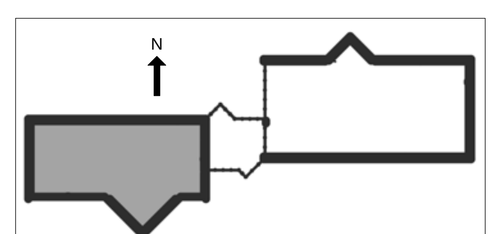
3/24/2016 2:34:30 AM



1 SECOND FLOOR - ADMINISTRATION
3/32" = 1'-0"

WPI

GATEWAY CAMPUS CENTER

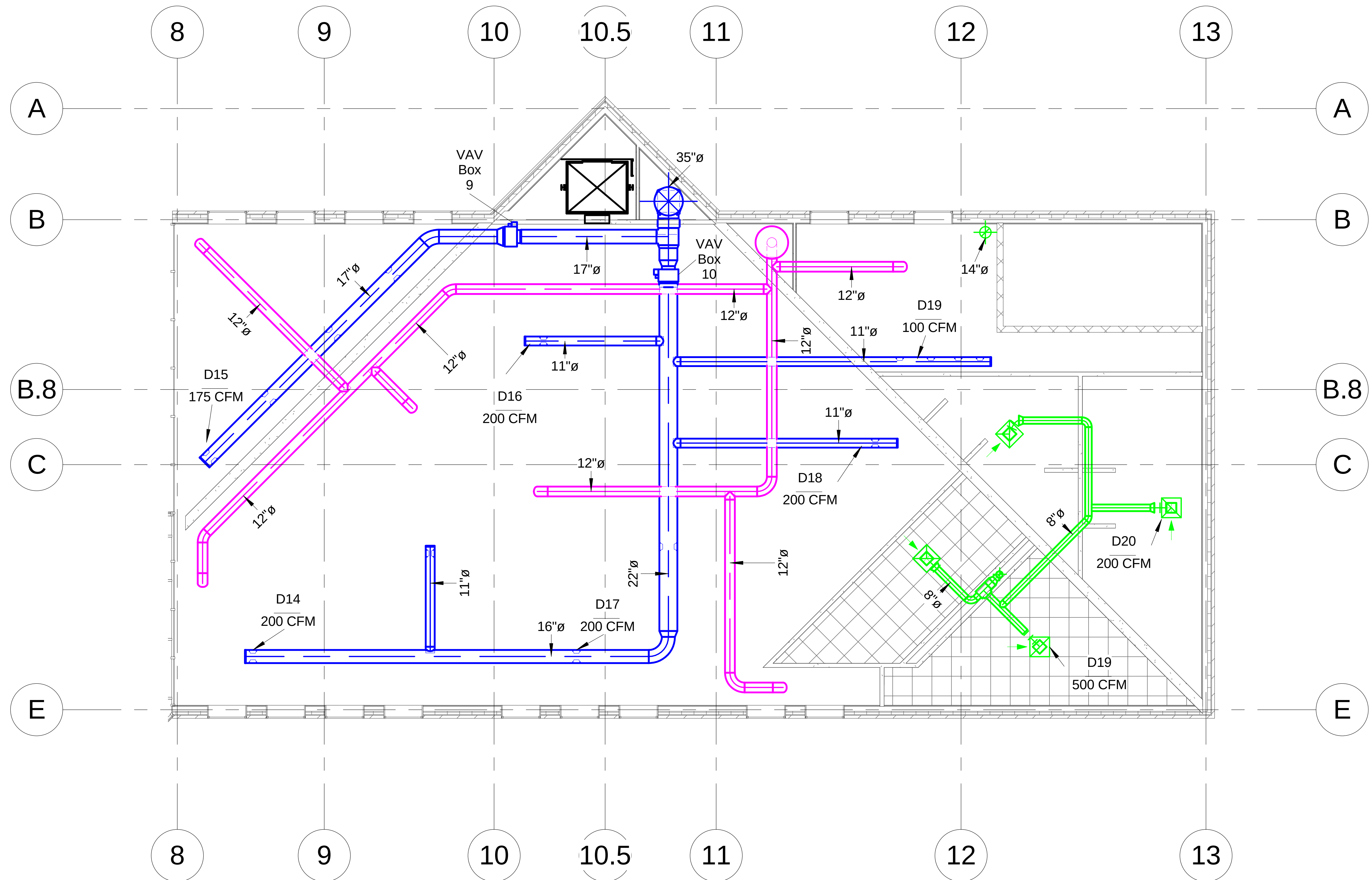


No.	Description	Date

SECOND FLOOR - ADMIN

Project number	Project Number	M-105
Date	Issue Date	
Drawn by	Author	
Checked by	Checker	Scale 3/32" = 1'-0"

3/24/2016 2:34:32 AM



1 THIRD FLOOR - STUDENT
3/32" = 1'-0"

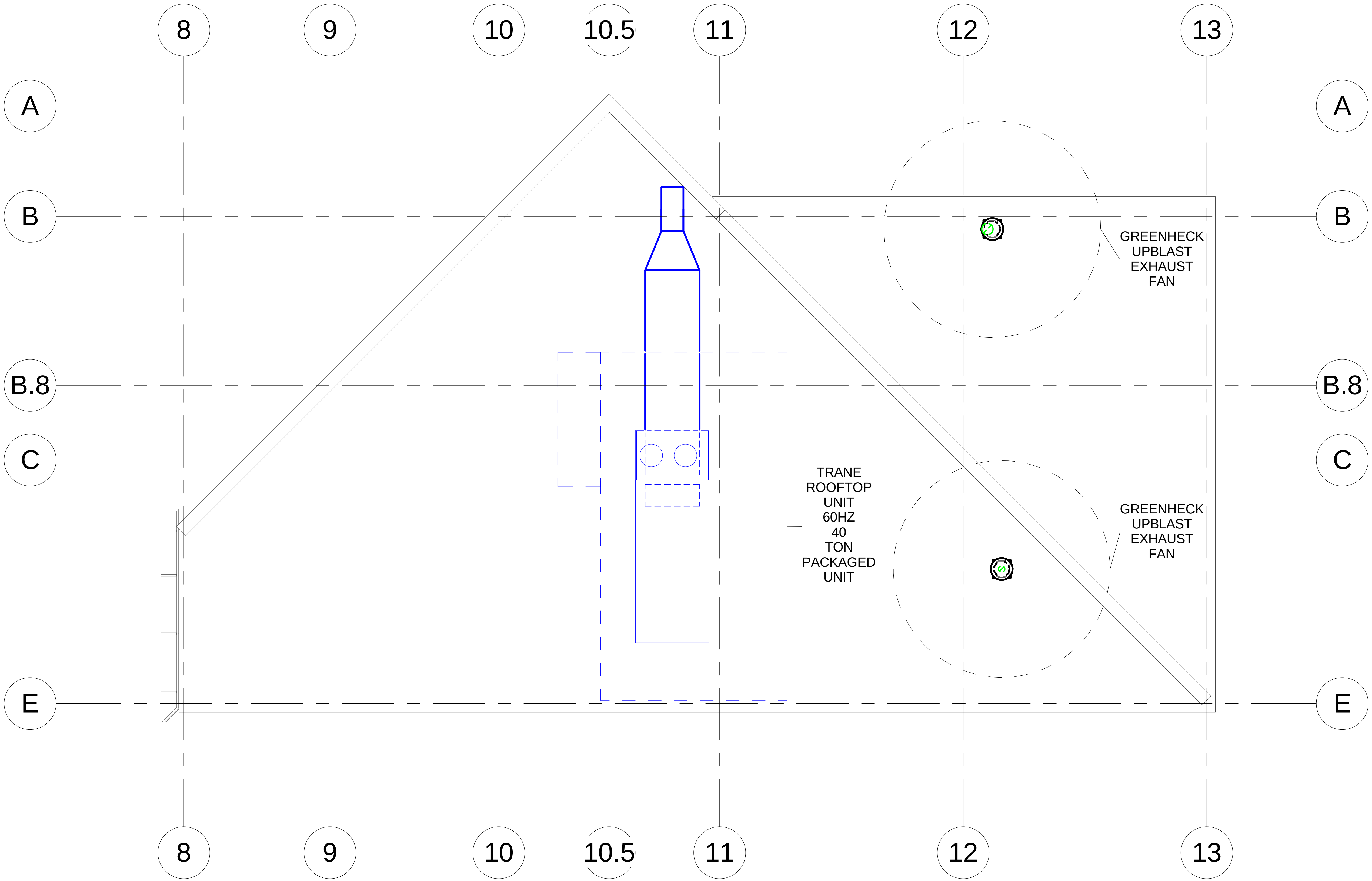
GATEWAY CAMPUS CENTER

No.	Description	Date

THIRD FLOOR - STUDENT

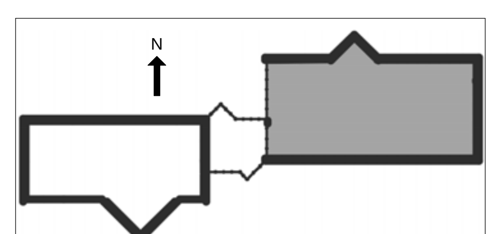
Project number	Project Number	M-106
Date	Issue Date	
Drawn by	Author	
Checked by	Checker	Scale 3/32" = 1'-0"

3/24/2016 2:34:33 AM



1 Mechanical 4
3/32" = 1'-0"

GATEWAY CAMPUS CENTER

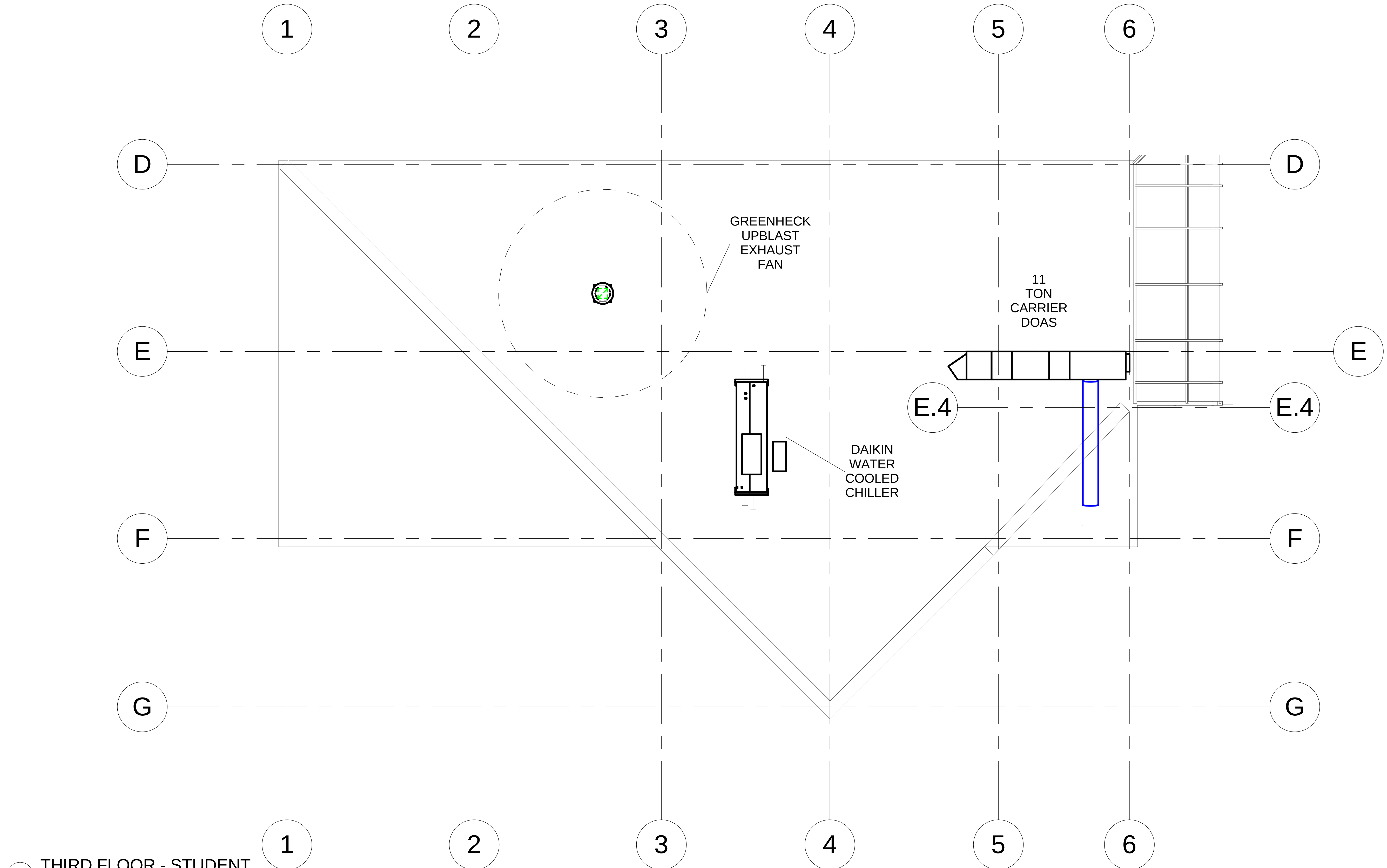


No.	Description	Date

ROOF - STUDENT

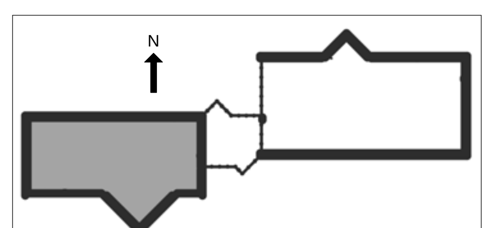
Project number	Project Number	M-107
Date	Issue Date	
Drawn by	Author	
Checked by	Checker	Scale 3/32" = 1'-0"

3/24/2016 2:34:34 AM



1 THIRD FLOOR - STUDENT
3/32" = 1'-0"

GATEWAY CAMPUS CENTER

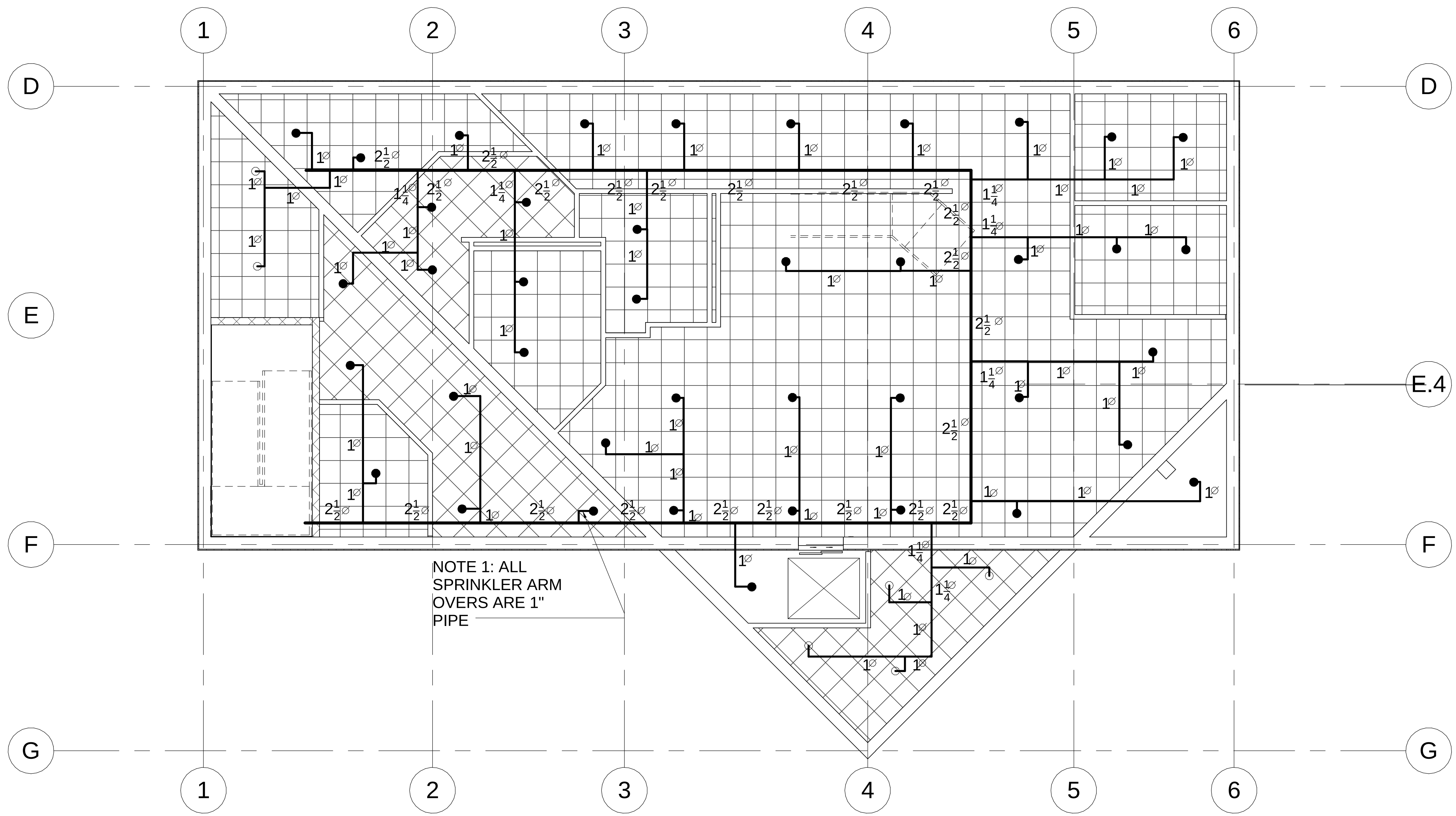


No.	Description	Date

ROOF - ADMIN

Project number	Project Number	M-108
Date	Issue Date	
Drawn by	Author	
Checked by	Checker	Scale 3/32" = 1'-0"

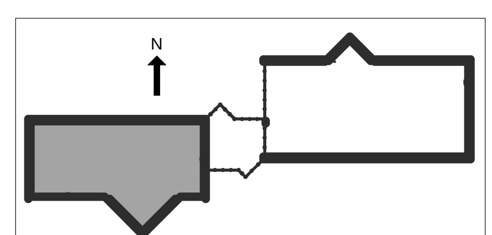
3/24/2016 2:34:35 AM



1 BASEMENT
3/32" = 1'-0"

WPI

GATEWAY CAMPUS CENTER



No.	Description	Date

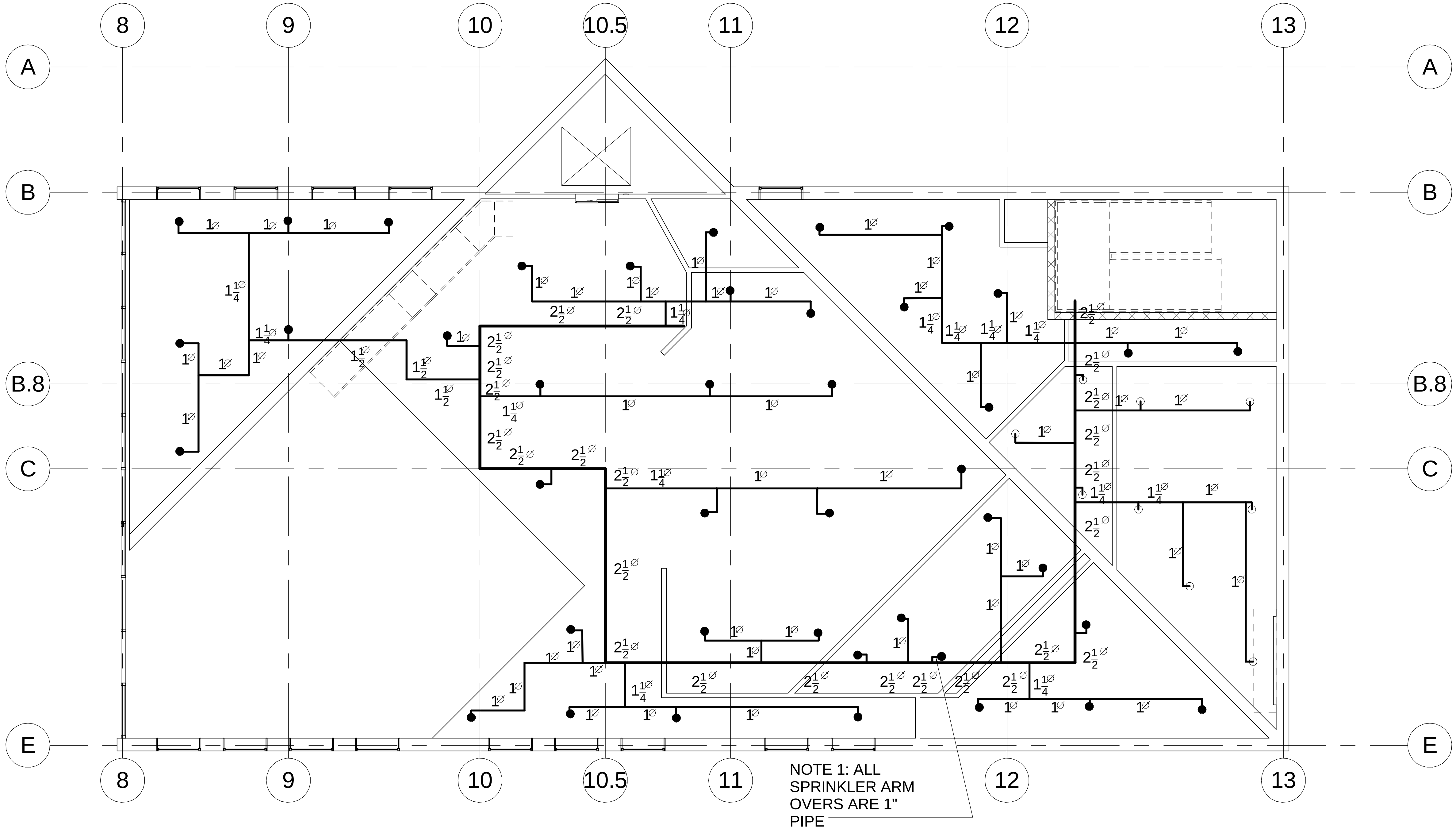
BASEMENT - ADMIN

Project number	Project Number
Date	3/3/16
Drawn by	JEP
Checked by	Checker

FP-101

Scale 3/32" = 1'-0"

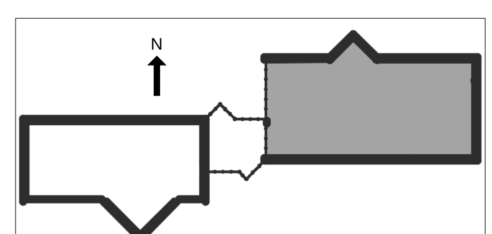
3/2/2016 10:28:45 PM



1 FIRST FLOOR
3/32" = 1'-0"

WPI

GATEWAY CAMPUS CENTER

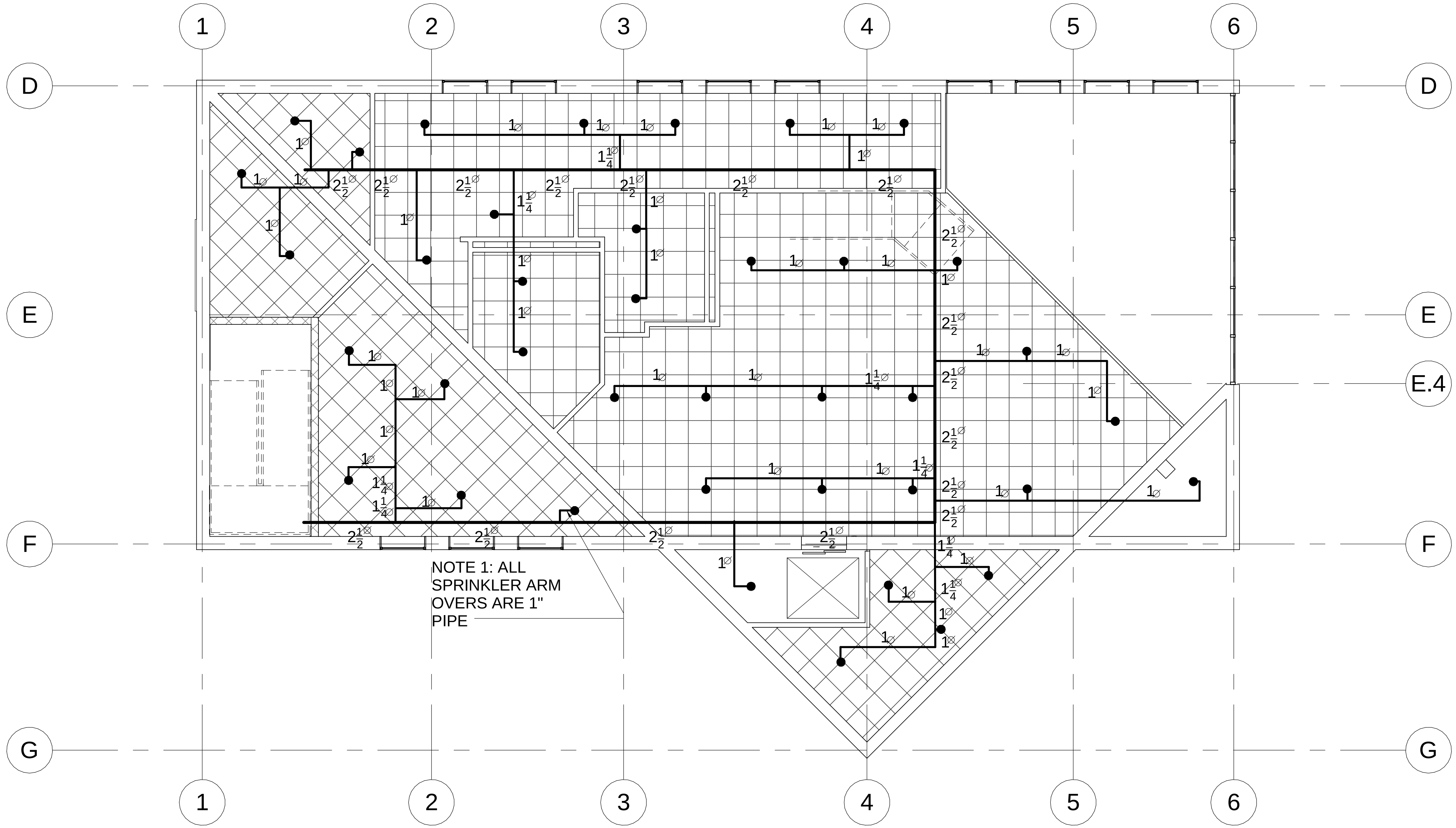


No.	Description	Date

FIRST FLOOR - STUDENT

Project number	Project Number	FP-102
Date	3/3/16	
Drawn by	JEP	
Checked by	Checker	Scale 3/32" = 1'-0"

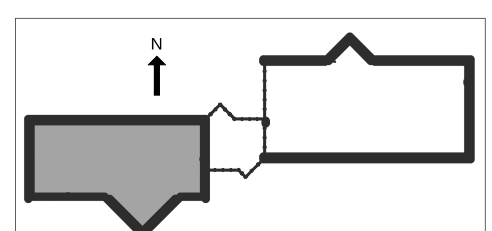
3/2/2016 10:28:49 PM



1 FIRST FLOOR
3/32" = 1'-0"

WPI

GATEWAY CAMPUS CENTER

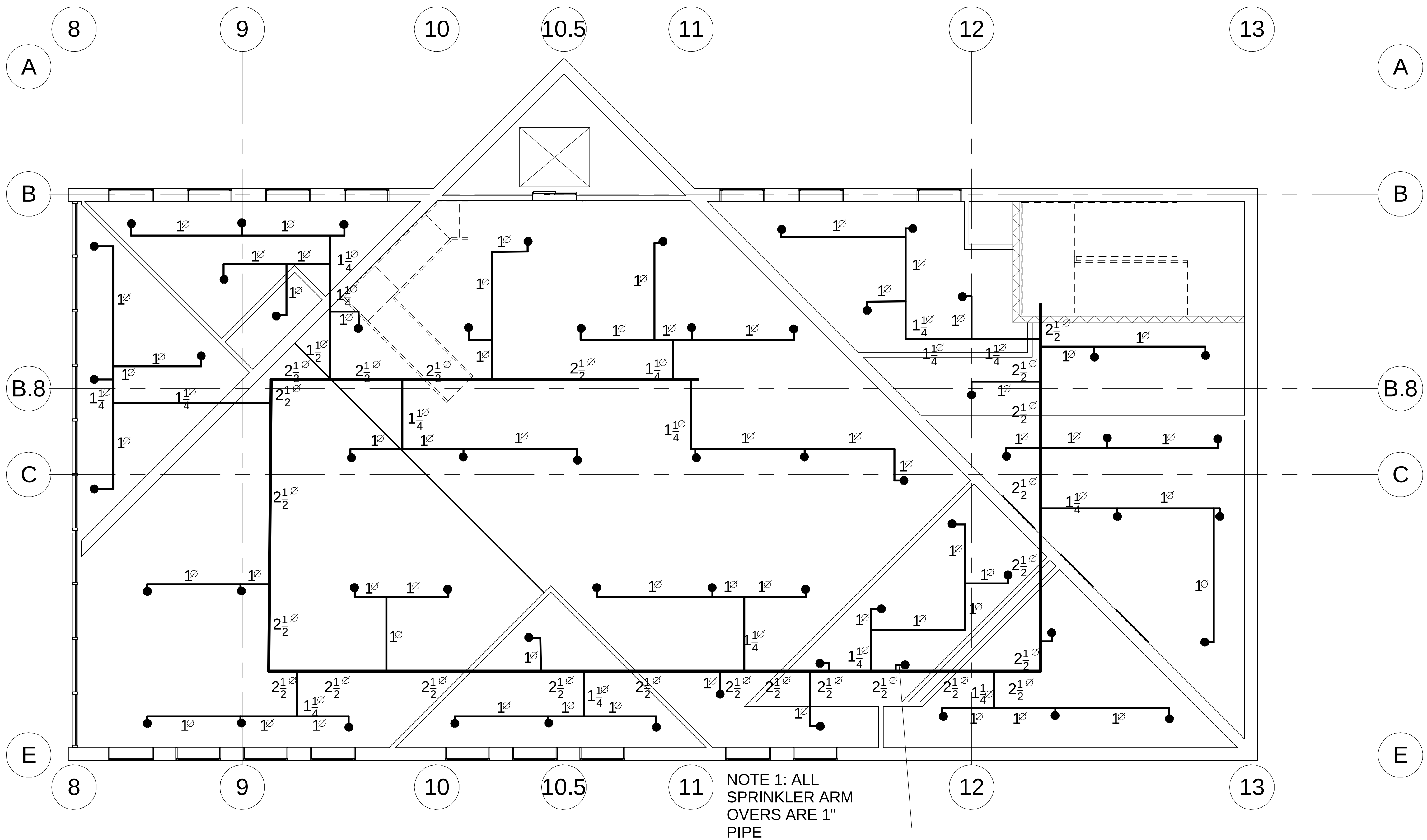


No.	Description	Date

FIRST FLOOR - ADMIN

Project number	Project Number	FP-103
Date	3/3/16	
Drawn by	JEP	
Checked by	Checker	Scale 3/32" = 1'-0"

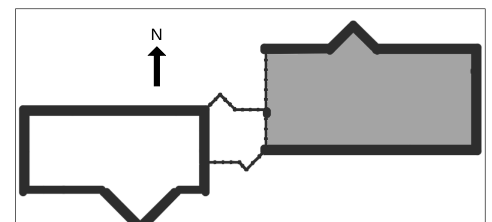
3/2/2016 10:28:49 PM



1 SECOND FLOOR
3/32" = 1'-0"

WPI

GATEWAY CAMPUS CENTER

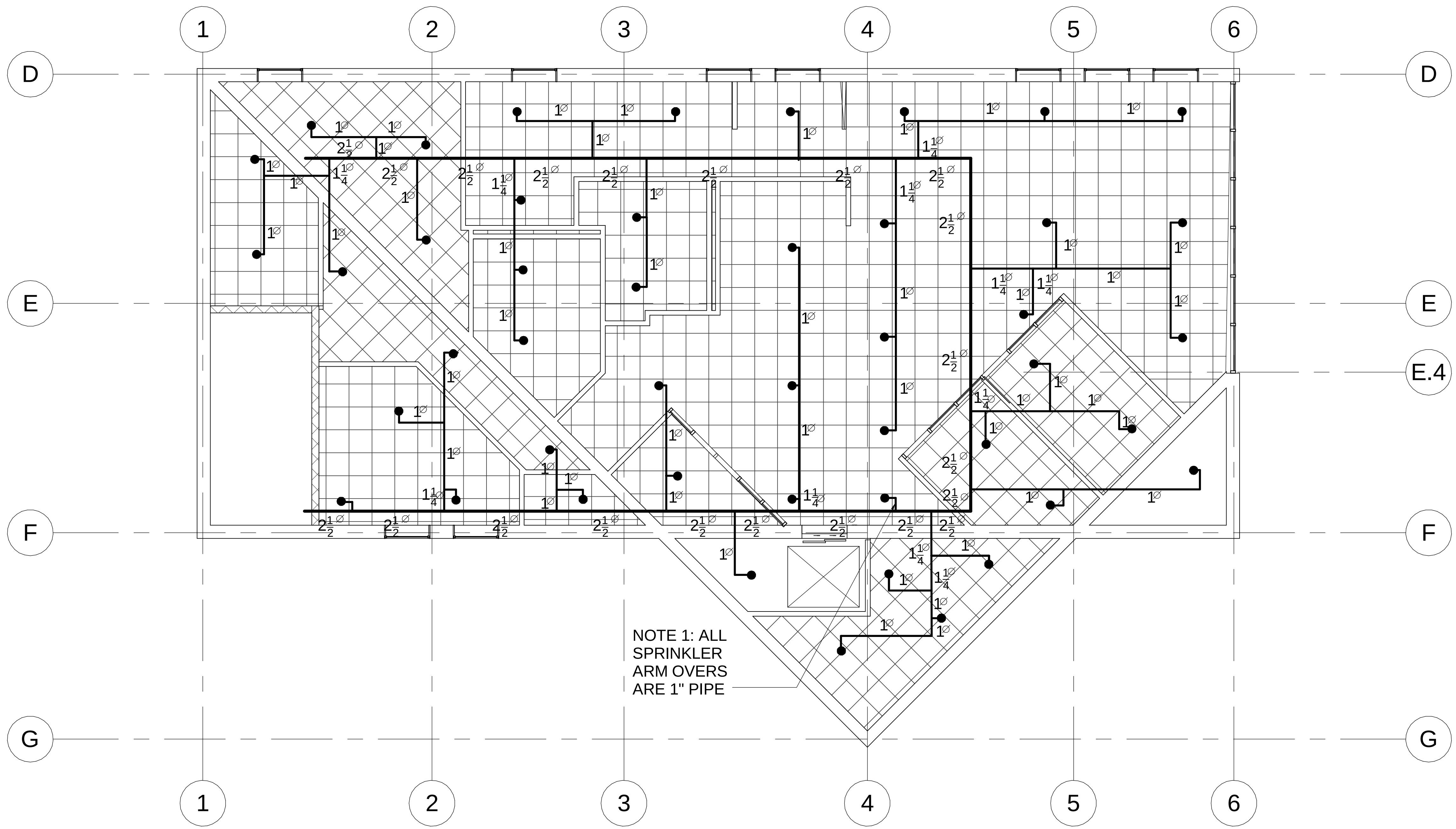


No.	Description	Date

SECOND FLOOR - STUDENT

Project number	Project Number	FP-104
Date	3/3/16	
Drawn by	JEP	
Checked by	Checker	Scale 3/32" = 1'-0"

3/2/2016 10:28:54 PM



1 SECOND FLOOR
3/32" = 1'-0"

WPI

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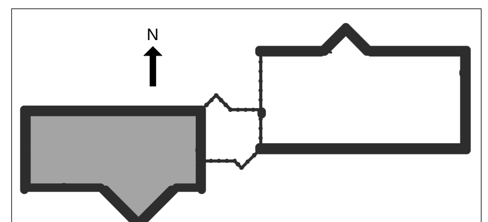
GATEWAY CAMPUS CENTER

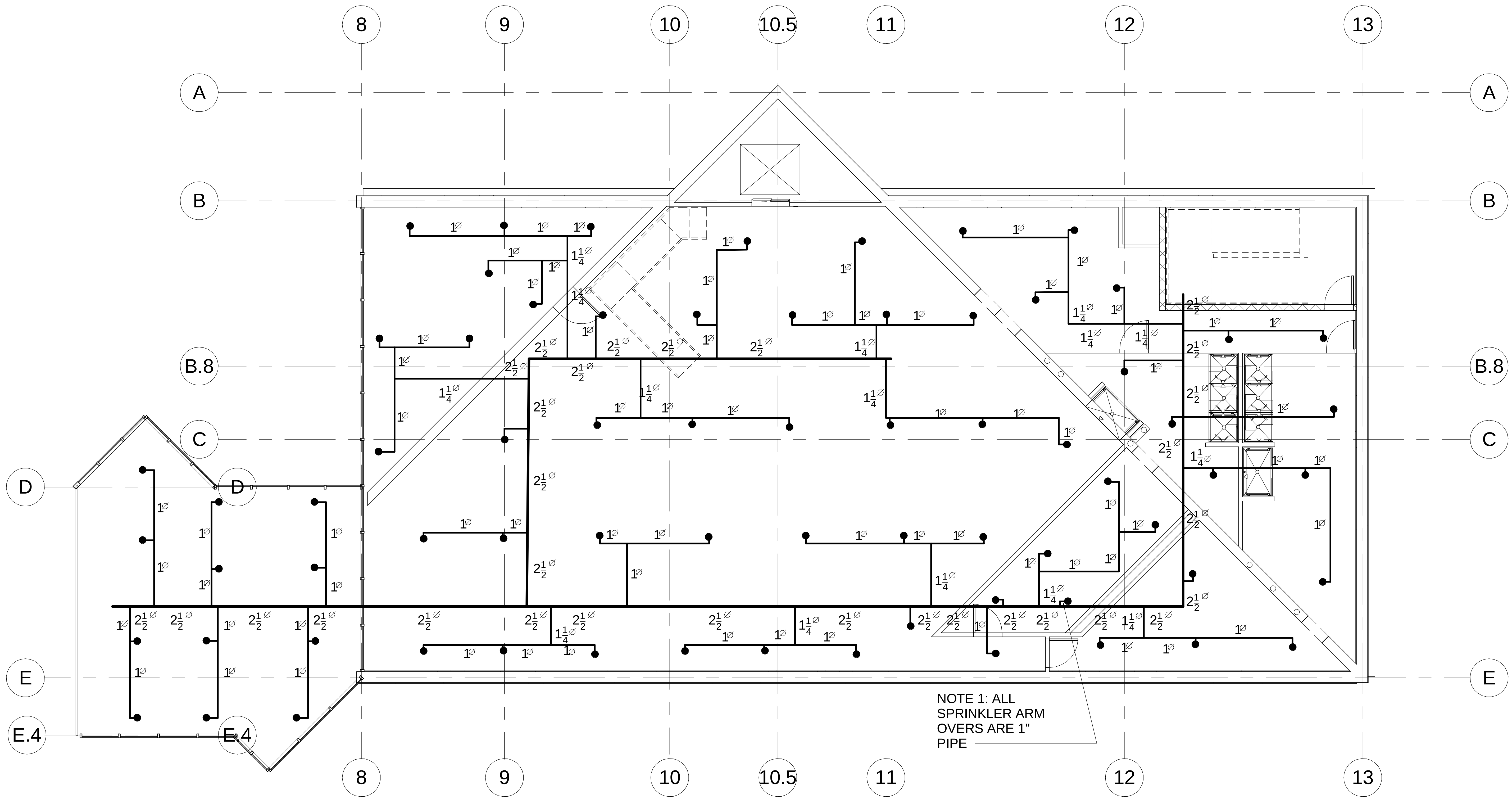


No.	Description	Date

SECOND FLOOR - ADMIN

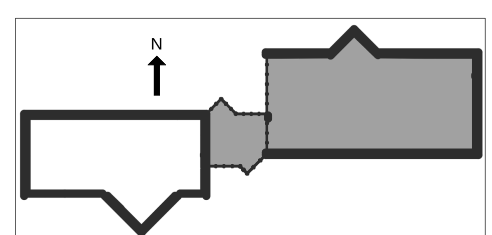
Project number	Project Number	FP-105
Date	3/3/16	
Drawn by	JEP	
Checked by	Checker	Scale 3/32" = 1'-0"

3/2/2016 10:28:58 PM



1 THIRD FLOOR
3/32" = 1'-0"

GATEWAY CAMPUS CENTER



No.	Description	Date

THIRD FLOOR - STUDENT

Project number	Project Number
Date	3/3/16
Drawn by	JEP
Checked by	Checker

FP-106

Scale 3/32" = 1'-0"

3/2/2016 10:29:02 PM