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Design of an Architectural Engineering Building for WPI's Campus

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Design of an Architectural Engineering Department Building for Worcester Polytechnic Institute

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

March 3, 2017

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This report represents work of WPI undergraduate students submitted to the faculty as evidence of a degree requirement. WPI routinely publishes these reports on its web site without editorial or peer review. For more information about the projects program at WPI, please see http://www.wpi.edu/academics/ugradstudies/project-learning.html

Abstract

This project consists of an architectural, structural, and mechanical design for a proposed Architectural Engineering building on Worcester Polytechnic Institute's campus. The goal of the building design was to promote group collaboration amongst students to align with the university's project-based curriculum. This project also incorporated a fire protection system, energy analysis, cost estimate and construction schedule. The team emphasized the importance of building code and proper coordination between disciplines to intuitively understand the integrative process of designing a building.

Authorship

The entire design team worked together to create the architectural design of the building. The structural team consisted of Meghan Hickey and Kimberly Marrion. The mechanical team consisted of Cassandra Tomerlin and Marc Toomajian. All members co-edited the report. The division of principal responsibilities and writing is as follows:

Meghan Hickey

- Chapter 1: Problem Statement, Site Location, Orientation and Shape
- Chapter 2: Architectural Design, Façade, Interiors and Finishes, Interior Walls and Furniture, Floor Finishes, Furnishings
- Chapter 3: System Selection, Gravity Loads, Live Loads, Dead Loads, Framing Considerations
- Chapter 5: Schedule

Kimberly Marrion

- Chapter 1: Introduction, Design Solution
- Chapter 2: Central Core, Column Line Layout, Windows, Curtain Wall
- Chapter 3: Structural Design, Gravity Loads, Live Loads, Dead Loads, Snow Loads, Lateral Loads, Wind Loads, Seismic Loads, Lateral Bracing, Horizontal Member Calculations, Curved Beam, Column Calculations, Bridge Structure, Foundation, Total Weight of Steel, Conclusion
- Chapter 5: Additional Considerations, Cost Estimate, RSMeans Square Footage Costs, Material Take-Off, Cost Comparison, Cost Breakdown

Cassandra Tomerlin

- Chapter 2: Code Compliance, Egress Requirements, Lighting
- Chapter 4: Mechanical Design, Load Calculations, U-Value, Heat Loss, Heat Gain, Peak Loads, Conclusion
- Chapter 5: Fire Protection, Sprinkler System Design, Egress Analysis

Marc Toomajian

- Chapter 2: Architectural Program, Utilization Efficiency

- Chapter 4: Zoning and CFM Calculations, System Selection, Layout and Sizing, Equipment Selection
- Chapter 5: LEED Evaluation, Energy Simulation

Meghan Hickey *Meghan Hickey*

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Cassandra Tomerlin *Cassie Tomerlin*

Marc Toomajian *Marc Toomajian*

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Ron, Facilities: For keeping the architectural studio in mint condition and taking care of us on our late work nights in the studio

Design Statement

The goal of this project was to demonstrate competency in creating an architectural, structural, and mechanical design of a proposed building to house Worcester Polytechnic Institute's (WPI) Architectural Engineering (AREN) program. This building would provide flexible learning spaces for the growth of the AREN department and WPI as a whole.

To create this united space, a multidisciplinary team was essential. The team was composed of four architectural engineers, two with a structural concentration and two with a mechanical concentration. Additionally, one of the architectural engineers with a mechanical concentration was in the process of pursuing a Master's Degree in Fire Protection Engineering, which was beneficial to the design team during the development phases. Each member contributed to the overall design of the academic building with his or her various skills and expertise.

The architectural design encompasses learning spaces for the general student body, specific studio spaces for the Architectural Engineering program, and additional faculty spaces. Collaborative and flexible learning spaces guided this design to include additional conference rooms, tech suites, and open study spaces to encourage group collaboration to align with WPI's project-based curriculum. The room layout, egress requirements, façade, and interior finishes and furnishings were all included in this architectural design.

The structural design of this building consisted of selecting the best-suited structural system, determining the loads acting on the system, and sizing an appropriate structure. After researching various types of structures, structural steel was selected due to its constructability and strength, which allow large spans to limit columns from impeding on functional space. The loads acting on the system due to member weights and permanent attachments, occupancy, and the environment were calculated in order to properly size the steel members. The variety of steel members was then reduced to several primary member sizes to limit the cost of the project and ease construction.

The peak heating and cooling loads were calculated based transmission, solar heat gain, and internal loads. Based on these peak loads, zones were assigned and CFMs were determined to select the proper system. Using a combination of an all-air and air-water systems, the ducts and pipes were laid out. Rooftop units and terminal boxes were selected to service the required loads throughout the building to ensure the comfort of the occupants.

Many additional considerations were addressed in the design of the building, including fire safety of the occupants, sustainability, constructability of the building, and the economic, social, and political implications of the project. To ensure the occupants of the building remain safe during an emergency, an automatic sprinkler system was designed. In addition, an egress analysis was performed to ensure all occupants would be able to safely exit the building in a timely manner. To aid in the fire protection of the building, noncombustible materials were used for the structure and finishes. A LEED evaluation was conducted to ensure that the building design considered various sustainability issues. Similarly, the energy analysis provided data regarding the energy usage, environmental impact of this building, and the cost of operation. The cost of operation is just one economic consideration of a new building. A preliminary cost analysis was performed to determine the cost of construction based on the square footage of the building and the materials and systems used. The building was designed considering the cost and constructability of materials in order to limit the duration of the project, ultimately limiting the cost and disruption to campus. A project schedule was created to determine that construction would likely take just over a year and a half. Lastly, the addition of a new building for WPI's campus could encourage more student applications and alumni involvement, influence more groupwork and collaboration, and enhance the social environment on campus.

The complete design of a building requires the coordination of many disciplines. The goal of this project was to successfully coordinate the architectural, structural, and mechanical systems of a building while incorporating additional aspects required to the success of the new academic space.

Executive Summary

The demand for additional student and faculty space is increasing with the growth of Worcester Polytechnic Institute's student body. Specifically, the Architectural Engineering department at WPI is growing immensely since its introduction to the university in 2012. With this university population growth and the specific growth of the Architectural Engineering program, the campus requires more space for both work and leisure. The purpose of this project was to create academic space that promotes WPI's theory of flexible learning while also providing a space to house the Architectural Engineering department.

Architectural Design

The purpose of the Architectural Engineering academic building was to meet all of WPI's academic needs while exploring the opportunities that flexible learning could provide to the student body. WPI's flexible learning curriculum recognizes that learning can occur in a variety of spaces. One of the main architectural design goals of this building was to provide new learning spaces that eliminate overcrowding throughout the rest of campus, especially in Kaven Hall. The architectural design goal of this building was to promote academic achievement through group collaboration.

Structural Design

Upon completion of the architectural design, the structure was designed to incorporate the following objectives: 1) flexibility, 2) constructability, 3) cost, 4) thermal performance, and 5) fire resistance. After determining that steel was the best-suited system for this project, the gravity loads were calculated based on the occupancy loads, construction materials, and snow. Then, lateral loads from wind, seismic, and soil were calculated. Both the gravity and lateral loads provided the necessary values required to size the structural members. Upon determining the weight of the structural members and the lateral loads, the concrete foundation and footings were designed. Lastly, the entire system was analyzed to provide the most effective structural solution for WPI's new Architectural Engineering building.

Mechanical Design

To keep the interior conditions comfortable for the occupants, this building was designed with two mechanical systems. However, before the system was chosen, peak heating and cooling loads for the rooms were determined followed by a zoning analysis that was dependent on the rooms' loads, functions, and orientation. These calculations allowed the system to be sized accurately to provide required comfort. In conclusion, an all-air system supplies the top two floors while an air-water system conditions the bottom two floors. While some engineers would argue that having two different systems servicing this building may not be the most efficient approach, these systems were selected in order to demonstrate competency in designing both duct and piping systems.

Additional Considerations

The complete design of a building requires more than the architectural, structural, and mechanical designs. In addition to these three major focuses, the following additional considerations were addressed:

- An egress analysis was performed on the building to map the circulation and flow of the occupants in the case of a fire or emergency. The circulation of the occupants was found to be smooth and have no disruptions within the floorplan.
- Sprinkler system layouts were designed to suppress potential fires long enough for the fire department to arrive and all occupants to evacuate safely.
- This building scored most of its LEED points from the Water Efficiency, Energy and Atmosphere, and Indoor Environmental Quality categories. The building received 66 points for a LEED gold rating.
- An energy analysis is a useful tool for estimating the energy use and operating cost of a building based on various materials. The energy analysis in Revit provides useful data such as energy use intensity and lifecycle cost.
- RSMeans Square Footage Costs and a Material Take-Off methods provided data that lead to a final cost estimate of approximately $10 million for this building.
- The overall construction duration of this building was estimated to approximately one and a half years.

The coordination of an architectural, structural, and mechanical design, along with the additional considerations, led to the successful design of an Architectural Engineering building to fit WPI's needs.

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1 Introduction

Worcester Polytechnic Institute (WPI) is a private research university in Worcester, Massachusetts, focusing on the instruction and research of technical arts and applied sciences. As WPI's student population continues to grow, the campus requires additional space for work and leisure. Specifically, the Architectural Engineering Department at WPI is growing rapidly, and there is a major need for more studio space, flexible learning space, and open workspace to accommodate the needs of this student body.

1.1 Problem Statement

At WPI, the academic curriculum was developed around a project-based learning model. Throughout the four-year curriculum, there is a Humanities and Arts Project, an Interactive Qualifying Project (IQP), and a Major Qualifying Project (MQP). These projects are based around small groups of three to five students collaborating to achieve a common goal. In addition, professors are encouraged to incorporate this project-based, collaborative group philosophy into their courses. Great Problem Seminars offer an initial opportunity for first year students to collaborate by addressing a real world problem in small groups. With the growth of the new Architectural Engineering program comes the opportunity to redefine how majors and programs at WPI are organized. The Architectural Engineering Department requires knowledge from many different disciplines: civil engineering for the structure of buildings, mechanical engineering for the Heating Ventilation Air Conditioning (HVAC) systems, electrical engineering for the electrical systems, and computer science for the communication and information technology. This interdisciplinary approach to learning requires a new, innovative building that allows for more flexibility and collaborative group work amongst students.

The purpose of this project is to create a conceptual design for additional academic space and to allow the Architectural Engineering Department to have a dedicated space outside of Kaven Hall. Kaven Hall currently houses the Civil and Environmental Engineering (CEE) Department and does not have enough classroom or studio space to provide for the entire Architectural Engineering program. As a new building on the WPI campus, the proposed building will not only provide more classrooms, studios, and lecture spaces, but also meet accessibility standards and ultimately promote WPI's motto of "Theory and Practice" with many collaborative, flexible learning spaces.

1.2 Design Solution

To fulfill this purpose successfully, the building design is based on three major ideas: 1) the expansion of WPI's campus, 2) the growth of the Architectural Engineering program, and 3) the improvement of group collaboration for a project-based learning experience. Each year, more and more students enroll at WPI. While more residence halls are being built, academic space is not expanding. To satisfy this need, this design includes additional lecture halls and classrooms on the top floor for use by all WPI students. To accommodate the growth of the Architectural Engineering program, this design includes a floor designated to Architectural Engineering students with adequate studio space, presentation rooms, and collaborative workspaces. In addition, as the program grows, so does the need for faculty. This building devotes a floor to the faculty with offices, conference rooms, a faculty lounge, and an administrative area. Lastly, the entire design was inspired by the need for more group collaboration spaces with each floor containing tech suites, conference rooms, and open study spaces suitable for collaborative research and design projects. In addition, the classrooms are designed with flexible learning in mind by allowing for rearrangement of furniture, in-class group work, and collaboration.

A successful design of a building includes the coordination of many components. The primary systems focused on for this project were the architectural design, the structural design, and the mechanical design. The architectural design must satisfy the major objectives of this building. The structural design must accommodate the architectural design while providing enough support for the loads acting on the building. The mechanical design must maintain a comfortable environment within the building to allow for learning, research, and project work. These three designs must be coordinated and synchronized in such a way to provide a successful overall design for an Architectural Engineering building on WPI's campus.

1.2.1 Site Location

WPI's 80-acre campus is located primarily between Institute Road and Salisbury Street. There are currently eleven academic buildings to house a wide variety of science and engineering disciplines. However, there is no building to fully support the growing Architectural Engineering program. The half-acre of land between the Gordon Library and Fuller Laboratories is an ideal site for this project as it will connect Kaven Hall to the rest of the campus. This location can be seen below in Figure 1 as denoted with a red arrow and in 3D in Figure 2. The connecting bridge between this new building and Kaven Hall makes the second floor of Kaven Hall accessible and fosters collaboration between the Architectural and Civil Engineering programs.

Figure 1: Location of Proposed Architectural Engineering Building on WPI's Campus

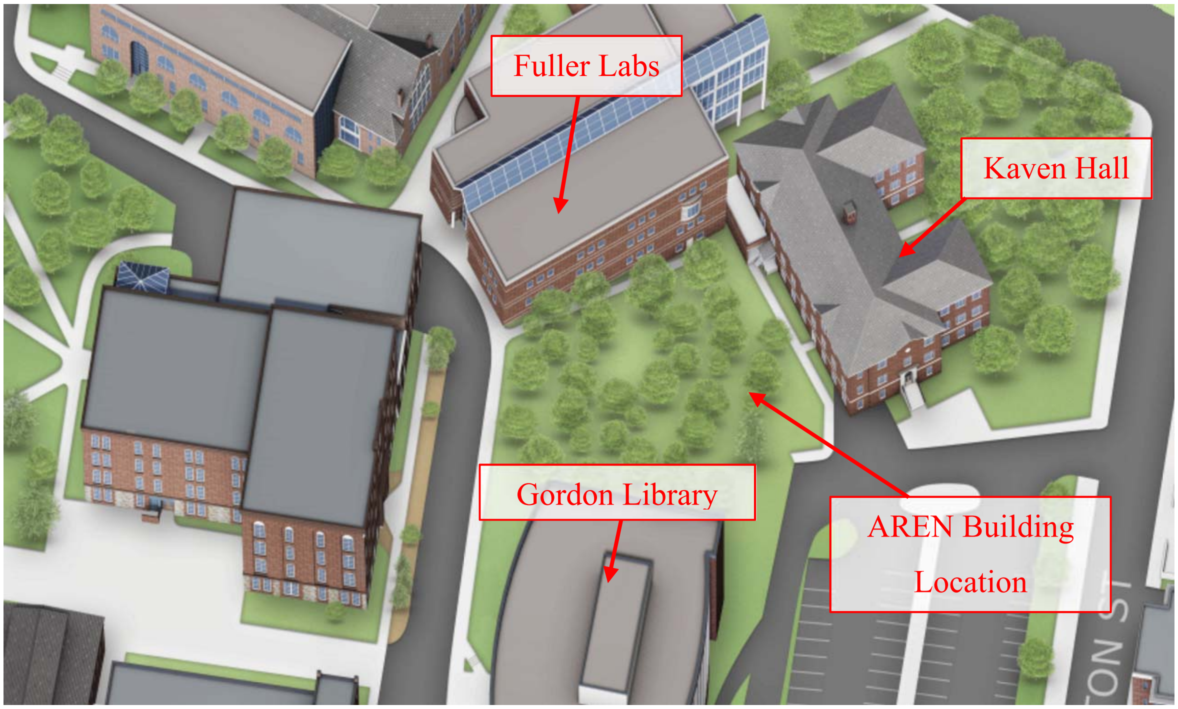


Figure 2: 3D Aerial View of Building Location

1.2.2 Orientation and Shape

The building, which is located on the central part of the site, has two main entrances. The southeast entrance is located on the first floor and is accessible from the parking lot located on Boynton Street. The other entrance provides access to the fourth floor from the upper road adjacent to the building. By locating the building in the center of the site, the project retains the existing staircase that connects the top of campus and the entrance to Kaven Hall. The circulation of the building on its site can be found below in Figure 3.

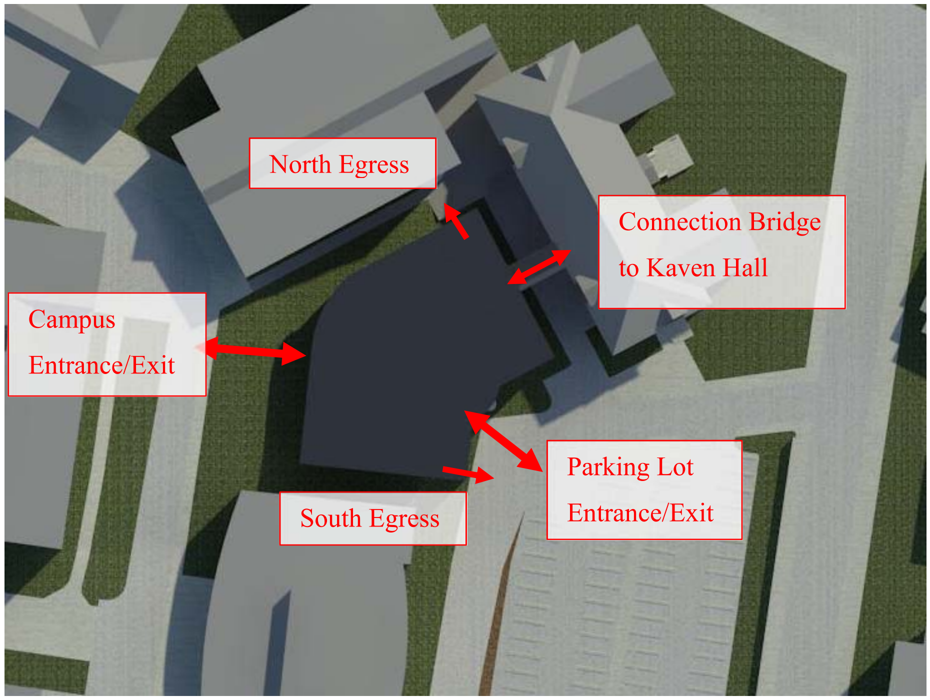


Figure 3: Main and Egress Access to the Building

The shape of this building has two major axes, one parallel to the road on campus and the second parallel to the Fuller Labs. These two major axes are connected with a curve to allow for smooth building edges. This design mimics the smooth movement of people who are walking on campus and make a right turn down the staircase to Kaven Hall. The side facing Kaven Hall was designed with a straight line parallel to Kaven that aligns with the ramp connecting the library parking lot and the staircase to campus. The facade of the building facing the library parking lot has two straight portions that meet at a curve, giving depth to the building while also allowing for a grand entrance.

2 Architectural Design

WPI's flexible learning curriculum recognizes that learning can occur in a variety of spaces. One of the main architectural design goals of this building was to provide new learning spaces that eliminate overcrowding throughout the rest of campus, especially Kaven Hall. The architectural design encourages student-faculty interaction and provides for study areas outside of the typical classroom setting. There are three types of academic spaces that the design team put special thought into designing: lecture halls, flexible learning classrooms, and architectural drafting studios.

2.1 Architectural Program

According to National Fire Protection Association (NFPA) and the *International Building Code* (IBC), this building is classified as a business occupancy due to the professional and office spaces for schooling higher than the 12th grade. The total occupancy load of the building is 913 people and is broken down by space in Table 1.

Table 1: Occupancy by Space

Space	**Total Occupancy**
Tech Suites	30
Classrooms	145
Conference Rooms	68
Lecture Hall	300
Studios	75
Presentation Room	85
Faculty Offices	13
Faculty Lounge	20
Admin Area	1
Copy Room	1
Computer Lab	50
TA Offices	20
Student Lounge	25
Open Spaces	80
TOTAL	**913**

There are two lecture halls located on the top floor of the academic building. The first lecture hall was designed to seat 200 students, while the smaller lecture hall is designed to seat

100 students. These large rooms are primarily used for scheduled classes of multiple academic disciplines with an extensive seating capacity. Both lecture halls will have a multi-media audio-visual system, with seats oriented toward the front of the room, and writing surfaces at each chair for the student. There is a total of four classrooms with three on the top floor and one on the third floor. These rooms will be used primarily for scheduled classes of multiple academic disciplines with a seating capacity between 30 and 45. These rooms are designed to have a multi-media audio-visual system with seats oriented toward the front of the room. These classrooms, however, comply with WPI's encouragement of flexible learning and will be equipped with rolling chairs and tables. Moveable furniture gives instructors and students the flexibility to rearrange seating into smaller groups during class. Additionally, there are several tech suites and conference rooms to promote WPI's educational goal of group collaboration. The full architectural program and floor plan for the fourth floor can be found below in and Figure 4 and Table 2.

Figure 4: Fourth Floor Plan

Table 2: Fourth Floor Architectural Program

Fourth Floor				**Gross SF =**	**11495**
Space	**Quantity**	**Occupants**	**SF/person**	**Required SF**	**Actual SF**
Tech Suite	1	6	25	150	164
Tech Suite	1	6	25	150	164
Tech Suite	1	6	25	150	158
Classroom	1	35	15	525	625
Classroom	1	40	15	600	669
Classroom	1	40	15	600	678
Conference Room	1	14	16	224	306
Conference Room	1	14	16	224	379
Lecture Hall	1	100	7	700	1136
Lecture Hall	1	200	7	1400	1597
Storage Room	1	-	-	83	83
Men's Bathroom	5			200	214
Women's Bathroom	5			200	214
Entrance		15			910
Open Area		15			596
Elevator					58
Egress North					347
Egress South					414
Totals		**491**		**5206**	**8712**

The third floor is dedicated mostly to the students in the Architectural Engineering program. There are three studio rooms designed specifically for the AREN students. Each of the three studios has a specific use: one for the sophomore-year design classes, one for the junior-year design classes, and the last for the senior-year students working on MQP over the course of the year. Each of these studios seat twenty-five students and will be equipped with a multi-media audio-visual system and individual drafting space for each seating area. The layout of each studio space is oriented so that students and professors can easily interact with one another for collaboration, critiques, and inspiration. The third floor also contains two presentation rooms, with capacities of 35 and 50 occupants, for the AREN students to display and formally present their projects. There is also a classroom and some additional tech suites. Another unique feature of the third floor is that it provides a bridge to the second floor of Kaven Hall. This addition makes the second floor of Kaven Hall handicap accessible. The architectural program and floor plan for the third floor are below as Figure 5 and Table 3.

Figure 5: Third Floor Plan

Table 3: Third Floor Architectural Program

Third Floor				**Gross SF =**	**11495**
Space	**Quantity**	**Occupants**	**SF/person**	**Required SF**	**Actual SF**
Studio	1	25	50	1250	1311
Studio	1	25	50	1250	1136
Studio	1	25	50	1250	1581
Tech Suite	1	6	25	150	187
Tech Suite	1	6	25	150	186
Classroom	1	30	15	450	547
Presentation Room	1	35	5	175	494
Presentation Room	1	50	5	250	482
Storage Room					83
Men's Bathroom	2			100	214
Women's Bathroom	2			100	214
Study Stairs		20			687
Open Area		15			645
Elevator					61
Egress North					347
Egress South					414
Bridge					
Totals		**237**		**5125**	**8589**

The second floor is dedicated to the faculty of the Architectural Engineering program. There are 13 faculty offices, along with three large conference rooms, a faculty lounge, an administrative area, and a 50-seat computer lab. Having all the offices and conference rooms on one floor facilitates collaboration amongst faculty. Also, having the faculty lounge on the same floor is convenient. While the floor is designed to accommodate the faculty, the additional space is utilized as a computer lab due to the lack of natural lighting on the second floor. This below-grade space is ideal for a computer lab as it limits glare on computer screens. Limiting sunlight also reduces solar heat gain, lowering the cooling demand for the computer lab, which is typically an excessive load. Figure 6 and Table 4 show the architectural program and floor plan for the second floor.

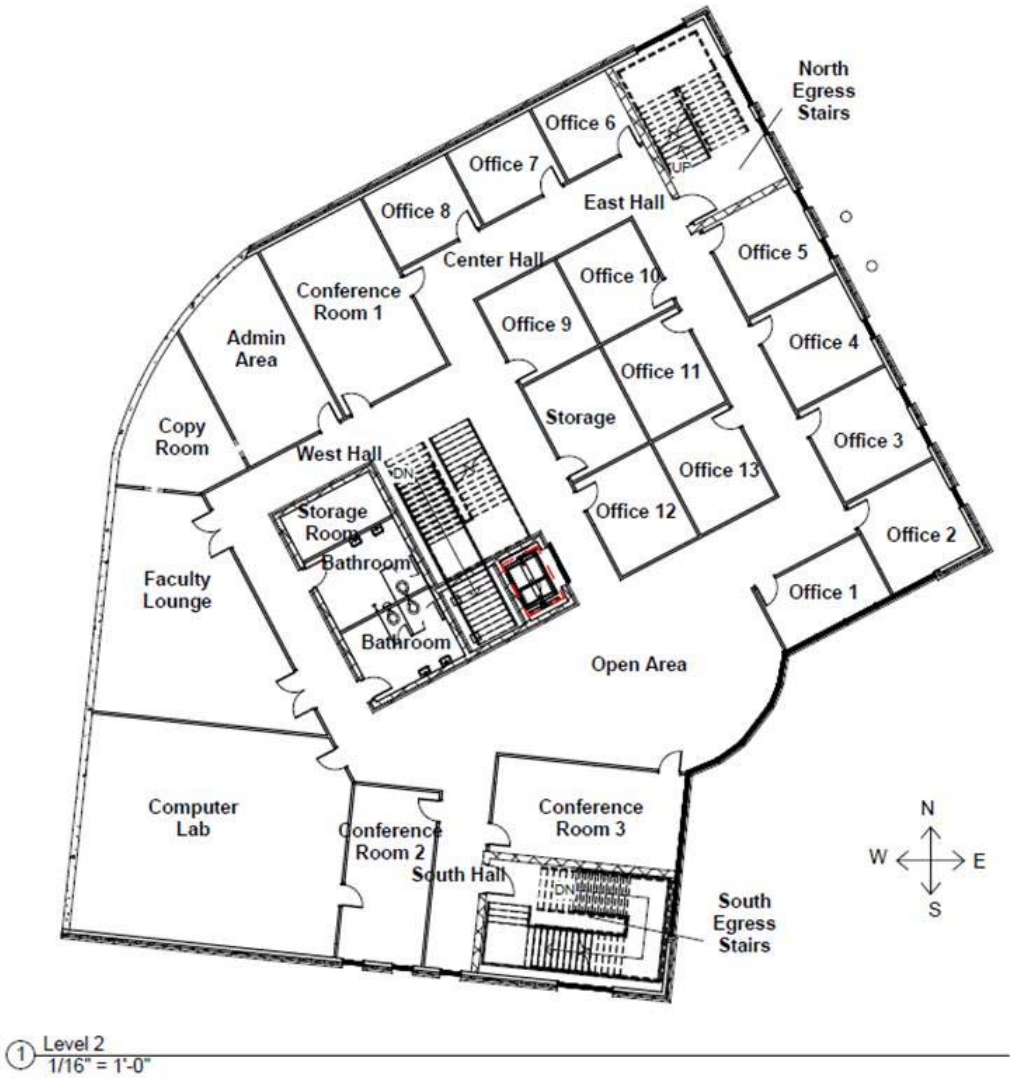


Figure 6: Second Floor Plan

Table 4: Second Floor Architectural Program

Second Floor				**Gross SF =**	**11495**
Space	**Quantity**	**Occupants**	**SF/person**	**Required SF**	**Actual SF**
Faculty Offices	13	13	130	1690	2425
Administrative Area	1	1	300	300	380
Faculty Lounge	1	20	15	300	765
Copy Room	1	1	100	100	246
Computer Lab	1	50	15	750	1157
Conference Room	1	15	16	240	379
Conference Room	1	10	16	160	295
Conference Room	1	15	16	240	442
Storage Room					83
Large Storage Room					190
Men's Bathroom	2			100	214
Women's Bathroom	2			100	214
Open Area		15			623
Elevator					61
Egress North					347
Egress South					414
Totals		**140**		**3980**	**8235**

The first floor consists of TA offices holding 20 occupants and a 25-person student lounge. The student lounge provides a casual study environment similar to that in Kaven Hall. As this space is often a popular workspace, a similar space was incorporated into this building. It is also strategically placed right next to the TA offices for the students' benefit. The student lounge extends to the left of the main entrance, as indicated in Figure 7, for additional study space. The first floor also houses the mechanical room and storage spaces as seen in the architectural program and floor plan, Figure 7 and Table 5, respectively.

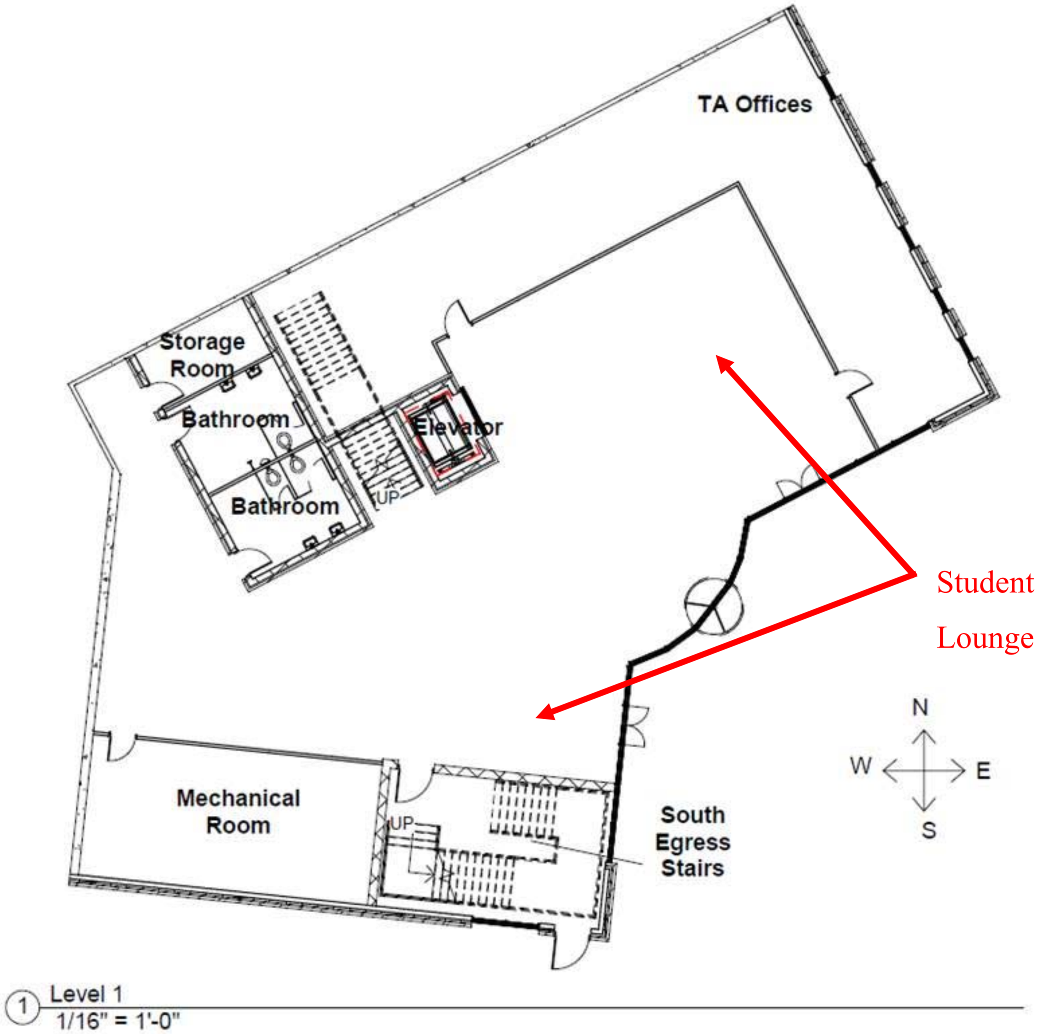


Figure 7: First Floor Plan

Table 5: First Floor Architectural Program

First Floor				**Gross SF =**	**6724**
Space	**Quantity**	**Occupants**	**SF/person**	**Required SF**	**Actual SF**
TA Offices Area	1	20	60	1200	1608
Student Lounge	1	25	15	375	3437
Mechanical Room	1		300	600	543
Men's Bathroom	2			100	214
Women's Bathroom	2			100	214
Elevator					61
Egress South					414
Totals		**45**		**2375**	**6491**

Each room was carefully designed in terms of its location within the building and its size and proportion. The classrooms and lecture halls were designed to be as close as possible to building entrance levels to improve access and reduce noise levels in other parts of the building. Large learning spaces like the lecture halls are located close to the building's primary entrances and exits, while all circulation spaces are large enough to accommodate the students exiting the room and the students waiting to enter the room for the next class. The location of classrooms and lecture halls in relation to natural lighting also needed to be considered. It is crucial for the architectural studios to have natural lighting to enhance a creative design environment. All three studios are on floors that are above grade to guarantee natural lighting through windows in each room. Learning spaces also need to be large enough to comfortably accommodate the number of students planned for each type of room with allowances for the types and sizes of furnishings anticipated for instructors, students, and any technical equipment.

Classrooms and lecture halls that are too wide make it difficult for instructors to maintain eye contact and typically set students up with poor sightlines. This is especially true for seats in the far corners of the room where the students are sitting too far away from the focal point of the lecture or presentation. Classrooms and lecture halls that are too deep make it difficult for student in the rear rows to interact with the professor teaching the class, hear the lecture, or see the projection screen or white boards. To encourage interactive discussion while providing good sightlines, classrooms and lecture halls that are square or nearly square almost always are the ideal design.

2.1.1 Central Core

Incorporating a central core into the structure of this building offers many benefits for the architectural, structural, and mechanical design of the building. The central core provides a location in the middle of the building to pick up lateral loads. Constructing a structural wall in the center aids in resisting lateral loads and carrying gravity loads, granting more flexibility in the architectural design and future adjustments. By placing the restrooms within this central core, all of the plumbing can be contained in these thicker core walls. This optimizes the usable space, as the interior partition walls do not need to be thicker to accommodate the required plumbing. In addition, locating the restrooms in the central core opens up exterior wall space for more windows and daylighting in other rooms in the building.

2.1.2 Column Lines Layout

In addition to providing lateral support, the central core provides a transition between the two major axes of the building. This column line layout, seen below in Figure 8 is designed to balance the flexibility of open spaces with the size of required girders for a given span distance. Figure 8, is designed to balance the flexibility of open spaces with the size of required girders for a given span distance.

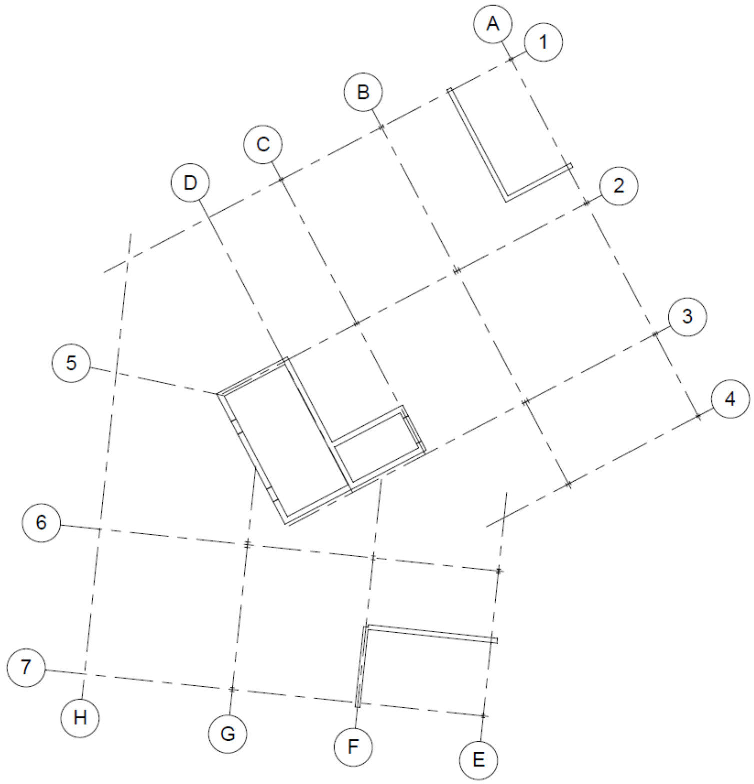


Figure 8: Column Line Layout

The central core allows for structural supports at the intersection of these two axes while maintaining perpendicular column lines in each wing. The column lines are parallel to each exterior wall at a span that aligns with the corners of the central core. There are two column lines between each pair of exterior walls to reduce the size of girders and allow for a central hallway. The central hallway provides walls for the columns to be built into, increasing the usable space in the building and providing flexibility for future needs. In addition, column lines are needed at the end points of the south curved curtain wall in order to provide structural support. Based on these column lines, the room layout was designed to allow for open spaces without columns.

2.1.3 Utilization Efficiency

Utilization efficiency is often associated with cost or profit for a building. Utilization efficiency is a measure of how much of the total floor area of a building is used for a program purposes. Classrooms, offices, and lecture halls are program spaces; corridors and stairs are necessary for a functional building but do not contribute directly to the program activities in the building. To improve the building utilization, corridor widths were limited. The sum of the areas of all program spaces (excluding restrooms, stairs, and corridors) divided by the total area of the building is 71.1% as shown in Equation 1:

$$\text{Utilization Efficiency} = \frac{\text{usable space}}{\text{total space}} = \frac{27377\text{ sf}}{38512\text{ sf}} = 71.1\% \qquad \textit{Equation 1}$$

This utilization efficiency of 71.1% demonstrates that the architectural floor plan balances better circulation and more open spaces with an appropriate use of functional spaces.

2.2 Code Compliance

The *International Building Code* limits the allowable height and area of new structures as well as additions to an existing structure. These codes are dependent on the type of construction and occupancy classification of the structure. This proposed building is classified as a business occupancy because the use is for education for students above the 12^{th} grade. The building is constructed of a noncombustible material, steel. The code states that noncombustible construction is of Type 1 or 2. Type 1 or 2 construction are further broken down based on the fire resistance ratings on the building elements, such as the structural frame, floor and roof construction, and nonbearing interior and exterior walls or partitions. Due to the high cost of fireproofing a steel structure, this building was designed with an approved automatic sprinkler system. Therefore, the construction type for this building is Type 2B, meaning it is noncombustible with no fire rating on any of the construction materials.

2.2.1 Building Height and Area Limits

According to the 2015 IBC, this building complies with the allowable building height and area limits. Listed below are the parameters these limits are dependent on:

a) Business (B) Occupancy Classification
b) Type 2B Construction
c) Automatic Sprinkler System throughout
d) 63 feet Tall
e) 4 Stories Above Grade Plane
f) 42,000 square feet

Table 6 below shows the building compliances for the allowable building height and area and number of stories above grade plane.

Table 6: Building Height and Area Code Compliance

	2015 IBC Table	Code Allowance	Building Design
Allowable Building Height	504.3	75 ft	63 ft
Allowable Number of Stories Above Grade Plane	504.4	4	4
Allowable Area	506.2	69,000	42,000 ft

2.2.2 Egress Requirements

Once the occupancy loads were calculated, it was pertinent to determine the egress requirements. The majority of the egress requirements depend on the occupant load of the building. The IBC codes and standards dictate where exits, stairs, corridors, and rooms can be placed in addition to the required dimensions of each.

2.2.2.1 Exits

In a business occupancy building, any space with a design occupant load of 50 or greater is required to have at least two means of egress by Table 1006.2.1 of the 2015 IBC. Because the occupant load for each floor exceeds 50, each floor requires two means of egress. The easiest way to satisfy this code requirement was to design two egress stairs. Additional code compliant exits were included for aesthetics and circulation.

Section 1007.1.1 of the 2015 IBC requires that the distance between the two furthest exits be at least one-third the maximum overall diagonal dimension of a sprinklered building. To meet this requirement, two egress stairs were positioned in opposite corners of the building. The first floor does not have the north egress stairs but has multiple exits on the southeast elevation as seen below in Figure 1. Exit 3 meets the one-third requirement as the distance between this exit and Exit 1 is more than one-third the overall diagonal dimension of the building.

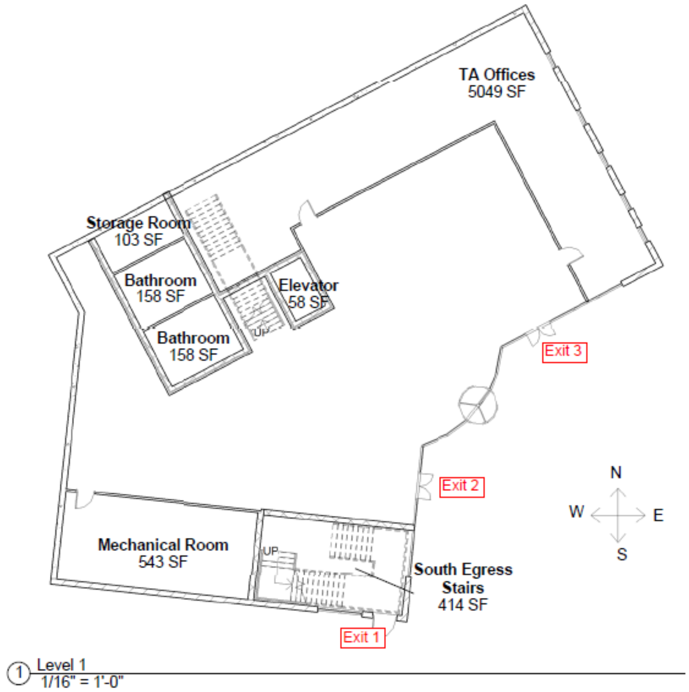


Figure 9: First Floor Exits

The exact width of these exits was determined by dividing the occupancy of the floor by the number of means of egress and multiplying that quotient by a capacity factor of 0.2 (IBC 2015: Section 1005.3.2). The fourth floor has the highest occupancy load of 491 with three exits yielding 163 occupants per exit. The required width per exit is therefore 33 inches. However, exit widths must be a minimum of 36 inches (IBC 2015: Section 1024.2). Because each exit on all the other floors has a capacity of less than 163 occupants, a 36-inch door is acceptable for every means of egress. Table 7, below, outlines the capacity and number of egress exits per floor. Therefore, all the exit doors in the building are a minimum of 36 inches as shown in the following calculations.

$$\text{Occupants per exit} = \frac{491}{3} = 163$$

$$\text{Required Exit Width} = 163 * 0.2 = 33 \text{ inches}$$

Table 7: Occupancy Capacity per Floor

Floor	Capacity	Number of Exits
1	45	2
2	140	2
3	237	2
4	491	3

2.2.2.2 Stairs

Egress stair dimensions depend on the occupant load as well. The tread of the stairs is to be a minimum of 11 inches with a maximum rise of 7 inches (IBC 2015: Section 1011.5.2). Egress stairs also must provide a minimum headroom height of 6 feet 8 inches and cannot rise more than 12 feet without an intermediate landing the same width as the stairs (IBC 2015: Sections 1011.3 and 1011.6). According to IBC 2015 Section 1011.2, the width of the stairs is required to be a minimum of 44 inches if the occupant load of the entire building is less than 2000 persons. To calculate the required width of the egress stairs, a process similar to the exit door width calculation is followed with a capacity factor of 0.3 instead of 0.2 (IBC 2015: Section 1005.3.1). Following this calculation, the minimum width of the stairs is 49.1 inches.

$$\text{Stair Width} = \frac{0.3 \text{ x } 491 \text{ occupants}}{3 \text{ exits}} = 49.1 \text{ inches}$$

Based on experiences on campus, this width might not be sufficient for the amount of circulation in staircases at high-traffic times, such as when classes change. Therefore, the stair width was increased to six feet wide to accommodate heavy traffic.

As stated above, there is a minimum requirement of two means of egress from each floor (IBC 2015: 1006.2.1). Originally, the building was designed to have one egress stair and one, on-grade exit door on each floor. However, these exit doors would need to be placed to match the slope of the hill. Lining these exit doors up with the grade of the hill would require different layouts on each floor. Having different egress locations on each floor would complicate column line and room layout. In addition, the hill is so steep that additional excavation would be required to create a safe, code compliant path away from the building. Therefore, the building was designed with two egress stairs instead of one egress stair with additional on-grade exits.

2.2.2.3 Corridors

Corridor width cannot be less than the egress component that it connects to (IBC 2015: Section 1005.1). This means that the corridor width depends on stair width and cannot be less than the 49.1 inches that was calculated from the greatest occupancy load. This width also satisfies IBC 2015: Table 1020.2, which states that corridors must be a minimum of 44 inches wide. Experiences in academic buildings and desire for an open academic building inspired the expansion of these corridors to seven feet. These seven-foot corridors will provide additional room for occupancy growth and display cases for project work while still meeting the code egress requirements.

2.3 Facade

When designing a new building in an established community like WPI, fitting the proposed building facade into the existing campus while still showing architectural growth and finesse is an important design goal. Most buildings on the WPI campus have some form of brick, so incorporating brick into the design was a driving consideration. Buildings on campus that display a balance of glass and brick, like the Sports and Recreation Center and Gateway Park, inspired the exterior architectural design.

2.3.1 Exterior Wall System

Four different façade systems were considered that would be consistent with the other buildings on and nearby the WPI campus: 1) terracotta, 2) precast panels, 3) Exterior Insulation and Finish Systems (EIFS), and 4) brick. While none of the buildings on WPI’s campus have terracotta panels, precast panels, or EIFS, the color and texture of each can be designed to look similar to brick material.

1) Terracotta panels are similar to brick in color but much larger and smoother (Figure 10). One major advantage of terracotta panels is the ability to provide continuous insulation behind the façade. However, terracotta is a very porous material that absorbs water and has been known to break and potentially fall off the façade during freeze thaw cycles.

Figure 10: Terracotta Panels Inspiration

2) Precast panels are a modern spin on old technology. Traditional bricks of various colors are embedded in concrete panels during the curing process. These precast panels attach to the building in a random pattern (Figure 11). While these panels provide a unique adaptation of the traditional brick façade, they are roughly three times more expensive than traditional brick and do not allow for flexibility in window placement as the panels are often only available at predetermined widths. It was decided that the window placement was more pertinent to the design than the façade system.

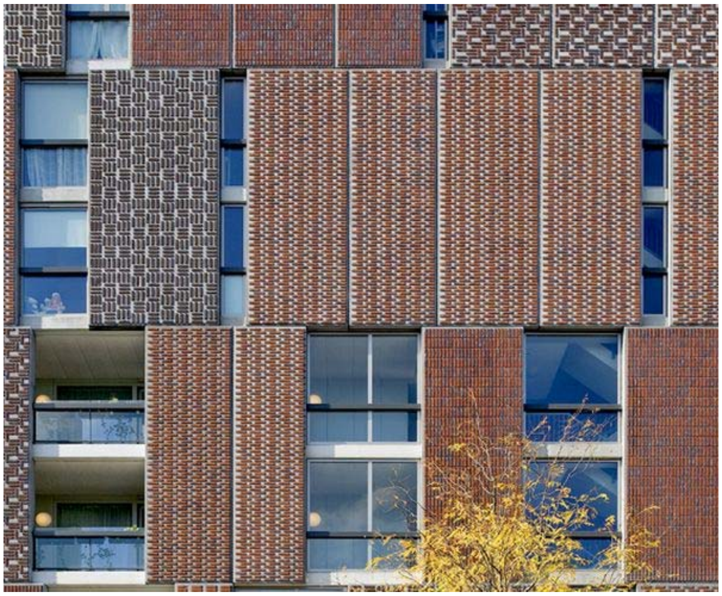


Figure 11: Precast Panels with Brick Inspiration

3) EIFS provide the lowest cost but the highest thermal performance. While the color could be customized to match the rest of the WPI campus, EIFS lack the traditional look of the rest of the WPI campus and especially those buildings adjacent to this site (Figure 12).

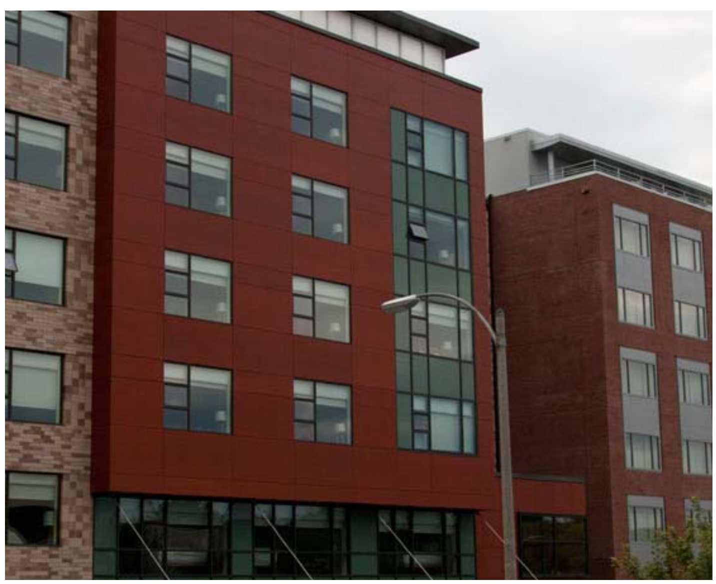


Figure 12: EIFS Inspiration

4) The brick façade system consists of non-traditional methods of stacking bricks with an offset to provide additional light into the building and texture on the exterior

(Figure 13). Brick is easily constructible and relatively low cost with acceptable thermal properties.

Figure 13: Brick Façade Inspiration

Based on these considerations, a traditional brick veneer façade was selected. Modern aspects were incorporated into the design through the curved curtain wall elements and scattered window design.

2.3.2 Windows

To increase the amount of daylighting in this building, tall and narrow windows were placed in functional positions based on the interior floor layout. A staggered pattern, seen below in Figure 14, was used to portray a more contemporary design and ensure that as many rooms as possible have daylighting. For example, due to the proximity of the offices on the second floor, the windows must be spaced closer together than would be necessary for a lecture hall.

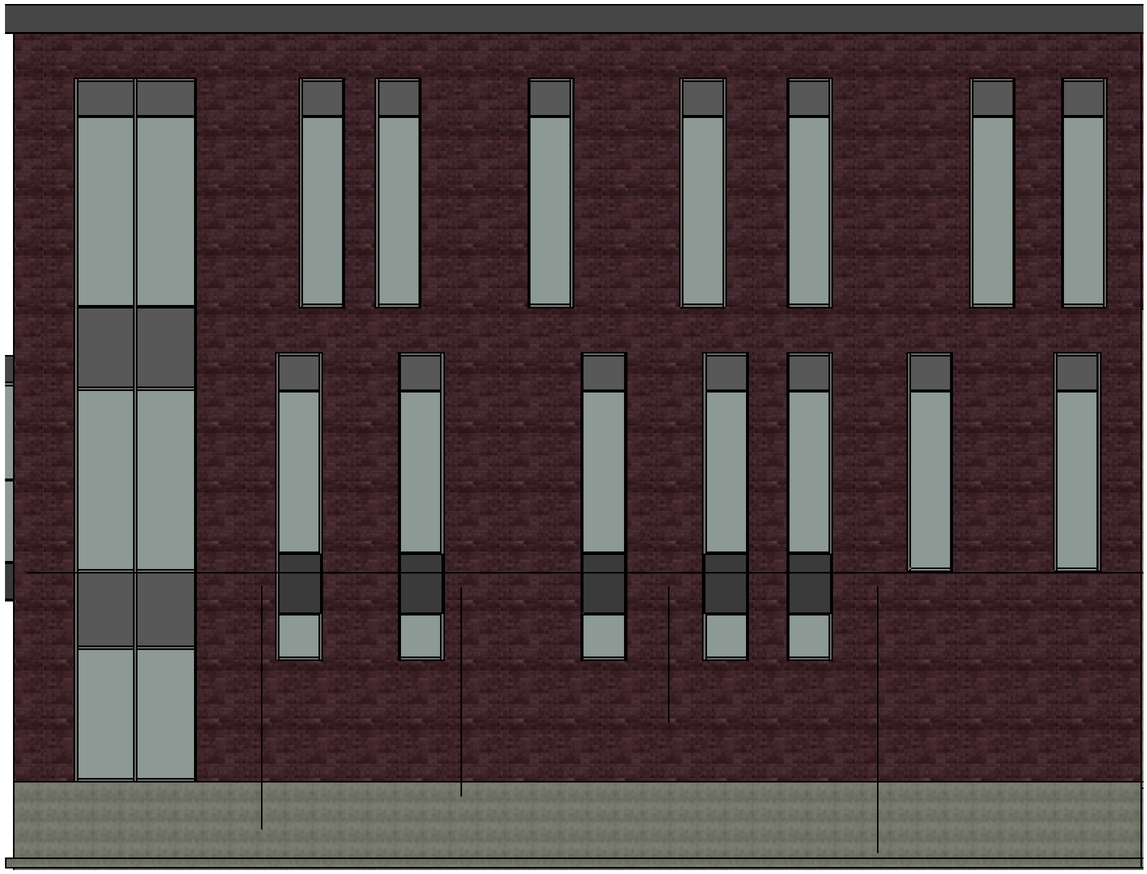


Figure 14: Window Layout

In addition, due to the steep slope of the site and inability to place windows on the west elevation of the first, second, and third floors, additional windows were included on the adjacent walls in the rooms along that elevation. Therefore, the window layout was designed based on the function of the interior spaces instead of an arbitrary spacing pattern.

2.3.3 Curtain Wall

The curtain wall component of this design provides large amounts of daylighting and a modern aesthetic to both the entrance from campus and the entrance from the parking lot. This large glass area remains consistent with the architectural design goal of incorporating modern features and the classical look of brick on campus. WPI seems to be moving towards the incorporation of large glass facades as seen in the relatively recent construction of the Sports and Recreation Center, East Hall and the design of the Foisie Innovation Studio. Based on the recent construction at WPI, the design team decided that a large curtain wall should be incorporated into both main facades of the building.

2.4 Interiors and Finishes

While designing the interior spaces for this academic building, it was important to keep in mind the overall goals of this project. The main purpose of this new addition to campus is to house the Architectural Engineering program and therefore provide architecture studios. These academic spaces need to have proper lighting to provide students and faculty with satisfactory academic performance. The finishes of the interior walls and flooring were also designed to aid in the functionality of the building. Lastly, the overall design plan incorporated WPI's idea of flexible learning, requiring carefully designed interior furnishing layouts for each space.

2.4.1 Lighting

The lighting for this building was designed with two fixtures. Type 1 (Appendix A) is a two-foot by four-foot troffer that is used in the rooms and large open areas. The 51W ArcLine fixture was chosen because it delivers 5,565 lumens to produce an efficacy of 109 lumens/watt. The selected luminaire is large and bright enough to reduce the number of fixtures needed for cost efficiency. This fixture has reflectors that help disperse the light throughout the room to avoid the issue of hotspots in the working environment. Type 2 (Appendix A) is a four-inch by four-inch recessed square downlight that is used in the hallways. The 20W fixture produces 1500 lumens to deliver 53 lumens/watt. Even though the efficacy is not as high as the Type 1 fixture, the BeveLED Connect Downlight was placed in the hallways to produce a more intimate and aesthetically pleasing setting. With less space and lower illuminance levels desired in the hallways, smaller fixtures are necessary to provide a comfortable environment for the occupants. Lighting plans for each floor can be found on Sheets E101-E104 located in Appendix Q.

Each room type has a recommended design illuminance level (Energy Trust of Oregon, 2013), measured in footcandles, that is dependent on the type of work being performed in the space (Table 8). For a school/university occupancy, the lighting design is standard to be under 0.87 W/ft^2 according to the 2015 *International Energy Conservation Code* Table C405.4.2(1). The building's total lighting wattage is 19,585 W with a square footage of 41,209 ft^2 which resulted in 0.47 W/ft^2.

Table 8: Lighting Level Design Criteria

Room Type	Footcandles (fc)
Office	40
Classroom	40
Conference	30
Corridor	25
Storage	20
Restroom	18
Breakroom	15

The Type 1 fixture is the two-foot by four-foot Metalux Arcline from Cooper Lighting (Appendix A). To determine the number of fixtures needed per room, the Room Cavity Ratio (RCR) was calculated. This value provides the designer with the ratio between the vertical wall area and the horizontal surface area. For irregular rooms, Equation 2 is used while Equation 3 is used for rectangular rooms. The RCR value is used to determine the Coefficient of Utilization (CU). CU is a main factor of determining the number of fixtures needed per room (Equation 4). Coefficient of Utilization is the fixture's efficiency in transferring the light to the working plane. Factors such as ceiling height and wall surfaces are important because reflectance levels from the light will differ. Tables to determine the CU values can be found in the specification sheet in Appendix A. There is a total of 305 of these fixtures used throughout the building. The complete lighting calculations can be found in Appendix B.

$$RCR = \frac{2.5 * H * P}{A}$$ *Equation 2*

$$RCR = \frac{5 * H * (L + W)}{A}$$ *Equation 3*

$$N = \frac{E * A}{n * F * LLF * CU}$$ *Equation 4*

In the equations above, H is the height between the fixture and desired work plane (2.5 ft above the ground), P is the perimeter of the room, A is the room's area, L and W are the length and width of the desired room, E is the design illuminance level, n is the lamps per fixture, F is the delivered lumens per lamp, LLF is the Light Loss Factor which is a standard of 0.8, and N is the number of fixtures. The second fixture used is the four-inch by four-inch BeveLED Connect from USAI Lighting. This fixture did not have a CU chart in the specification sheet, so the software, DiaLux, was used to decide the number of fixtures needed. DiaLux provides graphical representations of lighting levels depending on the size of the room, ceiling height, fixture mounting height, and fixture spacing. Lighting manufacturers produce IES files that contain photometric information for a specific luminaire. These files allow designers to import them into software like DiaLux in order to see how the fixtures will perform in the space. Figure 15 below shows the photometric results of the BeveLED Connect on a portion of one of the hallways. The fixtures in a row are spaced eight feet apart with another row staggered four feet away resulting in a total of 203 fixtures used throughout the building.

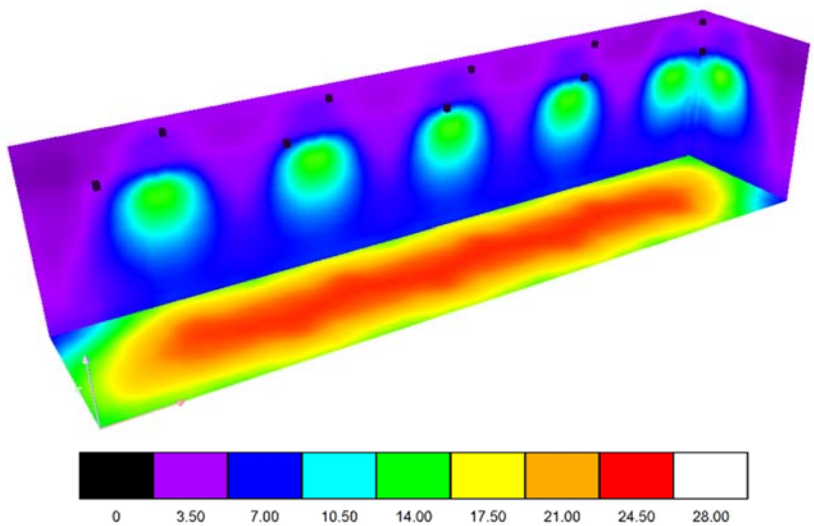


Figure 15: Graphical Representation of Illuminance Levels (fc) of Fixture Type 2 DiaLux Calculation

2.4.2 Interior Walls and Furniture

Wall surfaces in this academic building are gypsum board with a simple finish such as paint or a wall covering. In the emergency egress stairs, the walls are painted. The design team chose to work with gypsum board because of its noncombustible core, ease of installation, sound isolation, low price, and durability. When installed in addition to other materials in the wall and ceiling assemblies, gypsum board is effective in protecting the building elements from fire for a prescribed time period of Type IIB construction. Gypsum wallboards come in wide sheets in lengths of eight, ten or twelve feet, covering a large wall area at a time. It is also a lightweight material, making installation easy for workers to cover large areas in a short period of time. As mentioned previously, preventing the transfer of loud noises is essential to the design of an academic building, which is another reason why gypsum board is the ideal choice.

When choosing the interior wall and floor finishes of this academic building it was important to reference Chapter 8, "Interior Finish, Decorative Materials and Furnishings" in the 2015 IBC. This section of the 2015 IBC explains the limitations for the allowable flame spread and smoke development based on occupancy classification for the interior wall finishes chosen by the design team.

Many factors, including ignition temperature, smoke toxicity, and flame-spread, were considered when evaluating building materials. Flame-spread describes the surface burning characteristics of the building materials and is one of the most highly tested fire performance properties of the material. The American Society for Testing Materials (ASTM) is best known for developing a test for developing this rating. The tunnel test measures how far and fast flames spread across the surface of the building material. The scale is then divided into three classes and are used for flame-spread classifications.

2.4.3 Floor Finishes

Flooring materials and their assemblies provide a foundation for the interior space of the building. There are many factors that influence the material selection of a flooring system, specifically design intentions, human factors, health, safety, and maintenance. Flooring materials vary greatly with a variety of unique characteristics and performance considerations.

Carpets should be used in all areas where acoustics are a concern, most notably in academic working areas, as carpet is sound absorbent. The amount of foot traffic should be considered when selecting a carpet. Specifically, the hallways, entrance and exit areas, lobbies, and any other main area of circulation are considered to have severe foot traffic. Faculty and Teaching Assistant offices, study stairs, and lounge areas are considered to have heavy foot traffic while the conference rooms and tech suites for student group work have moderate foot traffic. Carpets with patterns can effectively mask or camouflage traffic patterns, spots, and dirt so that its appearance is maintained for a longer period of time. Therefore, carpet was selected for all the heavy traffic areas in this building.

Wood floors are another type of flooring system that the design team looked into for flooring in the academic spaces. Generally, hardwood floors cost more than carpeted floors, but they also require less maintenance, last longer, and can be repaired quickly. However, for high foot traffic areas, hardwood floors get scraped, scratched, scuffed, and dented very quickly. With this characteristic, the design team decided that wood flooring would be a poor choice.

Tile floors are highly durable and can typically be reused or recycled. Ceramic tile is known for its outstanding durability and ability to withstand heavy foot traffic that will outlast most other flooring materials. Because of the durability factor, there is little to no expense involved in future replacement costs. Specifically, vinyl-flooring tiles are able to withstand scuffing and scratching caused by the heavy foot traffic that happens in a university building. Vinyl floor tiles are available in a variety of color ranges and materials, which is why the design team chose vinyl tiles as one of the main flooring finishes within the building.

Elevators typically receive a high amount of foot traffic in a building. Their flooring finishes should relate to the entrance and lobby areas of the building, as they need to be durable. Hard surface floors are usually poor choice because they tend to be unstable because over time grouted materials will loosen or crack. Carpet or wood are better choices and perform well acoustically.

Stairways are used for general circulation and emergency exits and should have finishes that are consistent with the floors around them. In stairways used for emergency egress, unfinished or minimally finished surfaces are appropriate. For the central core stairs in this building, flooring for stairways, treads, and landings should provide acoustic control.

A breakdown of the floor finishes by space can be found below in Table 9:

Table 9: Floor Finishes by Space

Space	Quantity	Floor Finish
Tech Suite	5	Carpet
Classroom	4	Carpet
Conference Room	5	Carpet
Lecture Hall	2	Carpet
Storage Room	4	Vinyl Tile
Men’s Bathroom	4	Tile
Women’s Bathroom	4	Tile
Egress North	1	Vinyl Tile

Egress South	1	Vinyl Tile
Elevator	1	Carpet
Studio	3	Carpet
Presentation Room	2	Carpet
Study Stairs	1	Tile
Faculty Offices	13	Carpet
Administrative Area	1	Vinyl Tile
Faculty Lounge	1	Carpet
Copy Room	1	Carpet
TA Offices Area	1	Carpet
Student Lounge	1	Carpet
Mechanical Room	1	Vinyl Tile
Hallways	All	Tile (Vinyl)

2.4.4 Furnishing

Colors of finishes, furnishings, and equipment need to be fully coordinated in the design. Colors for finishes are selected from the palettes in the WPI's color guidelines and need to be compatible with successful color schemes in other academic buildings already on campus. Colors behind white boards and projection screens will be darker than in other areas to reduce the light reflections when projectors are in use.

The following space standards and furnishing types in Table 10 shall be used to estimate the total usable floor area of each type of room during this phase of the project.

Table 10: Furnishings by Space

Space	Furnishings Anticipated
Lecture Hall	Fixed writing surfaces & chairs
Classroom	Moveable tables and chairs
Studio	Drafting stations with computers & moveable chairs
Presentation Room	Conference table & chairs & presentation screen
Computer Lab	Computer Stations & moveable chairs & projector
Conference Room	Moveable chairs & conference table & computer station
Tech Suites	Moveable chairs & conference table & computer station

Furnishing layouts are produced during the design phase to ensure that room sizes and shapes will comfortably accommodate the number of occupants for each room. Room proportions have a significant impact on seating capacity, sight lines, and the ability of professors and students to interact with one another, no matter the size of the learning space.

3 Structural Design

Upon completion of the architectural design of this building, the structure was selected and designed to incorporate the following objectives and criteria:

1. Flexibility – The structure of the building should allow for the “flexible learning” spaces and accommodate future changes to the function of the building.
2. Constructability – Due to the location of the site, the structure of the building should promote ease of construction in order to reduce the duration of the project and disturbance to WPI’s campus.
3. Cost – The cost of the structure also needs to be considered in order to remain within WPI’s budget for the project.
4. Thermal Performance – The thermal performance characteristics also affect the structural selection considerations, as it was pertinent that the structure maintained the level of desired energy efficiency.
5. Fire Resistance – To ensure the safety of the students and faculty in this building and meet the Type IIB requirements the material selected must be noncombustible.

These five major considerations and the architectural design guided the selection of the type of structural system to be used, the determination of the loads acting on the system, and the selection and layout of the various structural members. After determining that steel was the best-suited system for this project, the floor live loads were calculated based on the occupancy and function of each space. These live loads drove the decisions for the deck design, which ultimately provided the dead loads of the system. After calculating the snow loads, the lateral loads from wind, seismic, and soil were calculated. Both the gravity and lateral loads provided the design values required to size the structural members. Upon determining the weight of the structural members and the lateral loads, the concrete foundation and footings could be designed. Lastly, the entire system was analyzed to provide the most effective structural solution for WPI’s Architectural Engineering building.

3.1 System Selection

Before sizing the structural members, a decision was needed regarding the type of structure to be used for this building. The structural system selected needs to support four floors, allow for large curtain walls, and provide flexibility in the use of the interior spaces. The major types of structural systems researched and analyzed were concrete, masonry, and steel. The benefits and downfalls of each system were compared in relation to the four major objectives of the structural design of this building: 1) flexibility, 2) constructability, 3) cost, 4) performance and 5) fire resistance. The results of this research are summarized below in Table 11:

Table 11: Comparison of Structural Systems

	Concrete	**Masonry**	**Steel**
Flexibility	• Allows for long unobstructed spans, creating open spaces and giving more flexibility to the design • Can be designed for most soil or seismic conditions (depends on the weight of concrete)	• Very flexible in terms of design and construction • Bearing wall construction does have a limit for renovations • Easy to renovate in the future	• Large column spacing on the building's interior can facilitate huge flexibility for the building's interior flow • Allows for the creation of open floor plans, especially in an academic setting • Any variations on site are difficult and expensive to resolve
Constructability	• Proper weather conditions needed for construction • Can be poured in any form	• The most important aspect is mixing mortar batches that are correctly and consistently proportioned to produce mortar with the appropriate strength and durability	• Fast construction • Steel framing is light and easy to transport • Weather conditions minimally influence the construction process • After being built, steel can withstand unfavorable weather conditions • Resistant to termites, cracks, splitting, and rotting

Cost	• Concrete itself is not relatively expensive, but the reinforcement and added construction time can add cost • Tends to cost less to insure	• Masonry materials are not very expensive, but the labor intensive construction can increase costs	• Cost less to insure • High quality building with a low cost and fast timeline • Cheaper because of the reduced risk of fire
Thermal Performance	• Very effective thermal mass • Absorbs and retains heat well • Problems due to condensation forming within the wall construction • Excessive spanning of areas by precast concrete foundation sections can lead to future water entry or floor slab movement	• Very strong, durable, and long lasting • Good thermal performance as materials typically have a high thermal mass • Limitations on how much insulation can be placed within the cavity walls	• Extremely durable and typically lasts longer than other materials • Typically requires less maintenance • Can be constructed with superior insulating systems, making steel structures very energy efficient
Fire Resistance	• In most cases, concrete does not require any additional fire protection because of its built - in resistance to fire. • Concrete is a non-combustible material that has a slow rate of heat transfer	• Provides great fire protection • Masonry is noncombustible and provides durable fire resistance	• Steel is non-combustible, fire resistant that will not feed a fire • Highly recommended building material due to its fire resistance characteristics

Concrete systems provide substantial structural support with a variety of different options in terms of cast-in-place concrete, pre-cast concrete, and a combination of the two. Cast-in-place concrete walls, however, do not easily allow for large curtain walls. Because thick, solid walls are needed for structural strength, the large, open spans required for curtain wall systems are impractical with cast-in-place concrete. The use of pre-cast concrete would be more practical with the curtain wall design as it allows for these large wall openings. However, to support pre-cast concrete beams on the top floors and the roof, the pre-cast columns would have to be very large at the base. This would limit the flexibility of the bottom floors and infringe on the square footage of usable space within the entire building. The thermal performance of concrete allows for concrete to absorb and retain heat well. However, the excessive spanning of areas by precast concrete foundation sections can lead to future water entry or movement within the floor slab. The biggest drawback to using concrete as the main structural system is that concrete does not withstand extreme weather well. High temperatures result in the rapid hydration of cement, increased evaporation of mixing water, and large volume changes resulting in cracks. The production of concrete in cold weather may cause severe damage if the concrete is exposed to the low temperatures which causes the pore structure to expand. Since Worcester, Massachusetts experiences a wide range of temperatures throughout the year, it would be difficult to use concrete as the primary building material. The concrete could not be poured in freezing temperatures, limiting construction to the warmer months. The unpredictable New England weather could negatively affect the construction of a concrete system and delay the project. Therefore, this building was designed to restrict the use of concrete to the footings, foundation wall, and slabs.

The second option analyzed was the use of masonry as the building structure. Incorporating a brick or masonry structure to the building could simplify both the structural and architectural design. The thermal performance of masonry is long lasting, strong, and durable because this building material has a high thermal mass. However, a major disadvantage to using a masonry structural system is the limit to how much insulation can be installed in the cavity wall. This is a major issue for buildings in the northeast with the extreme temperature differences. In order to accommodate for additional insulation, the size of the cavity wall would need to increase. Increasing the width of the cavity wall would reduce the interior usable square footage of the building. In addition, in order to structurally support the four stories of this building, the base of the masonry wall may need to be wider, further reducing the interior square footage. Lastly, brick and masonry construction conflicts with curtain walls, as there is no interior structure for the curtain wall to attach to and hang from. Similarly, structural masonry units bear on the units below, which would require complex details for the areas above and around the windows and curtain walls. Therefore, the design team chose not to build with a masonry structural system.

The final option researched was a steel structure. Steel allows for the flexibility in the interior spaces as the allowable span between members exceeds those of the other options. There are many advantages to erecting steel buildings such as fast construction time, reduced impact from weather, cost, and fire protection. Steel construction is lighter than concrete, wood, and brick building materials. It does not easily warp, is not edible by termites or other pests, and most importantly, cannot ignite, making it the safest building material. While steel construction does not require hourly fire resistance to meet the requirements for Type IIB construction, some form of fire protection, such as a sprinkler system, is still required. Although incombustibility is not unique to steel, it is an additional benefit that makes steel more desirable than other materials. The thermal performance for steel is extremely durable and lasts longer than other materials. Additionally, steel's thermal performance allows for a building to be constructed with superior insulating systems, allowing for steel buildings to be very energy efficient. Steel has been used for construction projects similar to this building for many years. Based on the four major objectives of the structure design, 1) flexibility, 2) constructability, 3) cost, 4) performance and 5) fire resistance, steel was selected for the structure of this building because it more closely aligned with the goals of the project than the other researched materials.

3.2 Gravity Loads

Loads are representative of the forces that act on the structural framing of a building. The structure must be designed to support and carry these loads from the roof of the building to the foundation. Various types of loads are treated differently within the structural design requirements stated within the 2015 IBC. Specifically, gravity loads act in the direction of gravity or vertically on the system. Gravity loads are broken down into three major categories: 1) live loads, 2) dead loads, and 3) snow loads.

3.2.1 Live Loads

Live loads account for any non-permanent loads acting on the system. These loads include the loads from people, furniture, and any structures that can possibly be moved in or out of the building, such as interior partitions. As mentioned in the architectural section, this building has a large amount of space devoted to "flexible learning" where there is no predetermined classroom setup, allowing the rooms to be used for different purposes. Based on this objective, the building was designed for the 100 pounds per square foot (psf) occupancy live load required for assembly areas with moveable seats in Table 1607.1 of the 2015 IBC, recreated below as Table 12. This live load allows for the flexibility required to adjust room layouts to fit multiple functions.

Table 12: Minimum Uniformly Distributed Live Loads from Table 1607.1 of the IBC

Occupancy or Use	Uniform Load (psf)
4. Assembly Areas	
Fixed seats (fastened to floor)	60
Follow spot, projections and control rooms	50
Lobbies	100
Movable seats	100
Stage floors	150
Platforms (assembly)	100
Other assembly areas	100
31. Storage Warehouse	
Light	125

In addition to the live loads acting on the structure when the building is occupied, live loads from construction activities before the building is occupied must also be considered. However, because the construction activities and the occupancy of the building never occur at the same time, the larger of the two loads is selected as the design load. Since the occupancy load of each floor, 100 psf, is greater than the construction load generally used in the industry, 25 psf, the structure is designed to support 100 psf per floor. The first floor requires a higher uniform live load due to the heavy equipment located in the mechanical room. Table 1607.1 of the 2015 IBC does not have a use that directly aligns with the first floor mechanical room, so the uniform live load of a storage warehouse with light use was selected as the most similar use and used as the first floor's live load. The summary of the live loads can be seen below in Table 13:

Table 13: Live Loads

Floor	Occupancy Load	OR	Construction	**Total Live Load**
1	125	OR	25	**125**

2	100	OR	25	**100**
3	100	OR	25	**100**
4	100	OR	25	**100**
Roof	See Section 3.2.3 Snow Loads			**42.35**

3.2.2 Dead Loads

The dead load on a structure includes the weight of all permanent loads acting on the system. These loads include items that are permanently attached to the structure and the self-weight of the structure. Some of these items include ceilings, mechanical and plumbing systems, flooring, beams, columns, floor slabs, exterior walls, and roof. The first major dead load acting on the system is the floor slab, composed of lightweight concrete and metal decking. The steel deck acts as both formwork for the concrete and a structural component itself. The decking and slab span the distance between horizontal members to distribute the uniform loads to the horizontal members, which then transfer the load to the columns and down to the ground through the foundation. Therefore, the decking must support the weight of the wet concrete while it cures and the associated live loads from construction activity. Once the concrete has cured, the combined slab and decking must support its own self-weight and the weight of the superimposed uniform dead and live loads.

In order to meet the minimum 1-hour fire resistance rating required for Type 2B construction, at least 2.5 inches of lightweight concrete must be between floors according to Table 721.1(2) in the 2015 IBC. Having determined the thickness of concrete, the metal decking could be selected from various options provided by Vulcraft in their extensive design guide and catalog. In order to align with the flexible learning space objective, the decking with the maximum span length for composite decking, the 3VLI decking, was selected out of the various Vulcraft VLI options. While the 1.5VL, 1.5 VLR, and 2VLI decking all have spans that would satisfy the maximum span of 12 feet between horizontal members, these options would require more than 2.5 inches of lightweight concrete or normal weight concrete to sustain the design live load of 100 psf. The 3VLI decking provides spans greater than 12 feet with the minimum 2.5 inches of lightweight concrete with live loads greater than 100 psf. The large span length of the 3VLI decking also reduces the size and number of steel members needed, ultimately lowering the total cost of steel. With a 2.5-inch lightweight concrete slab, the combined weight of the concrete and 3VLI metal decking is 39 psf, as seen below in Table 14.

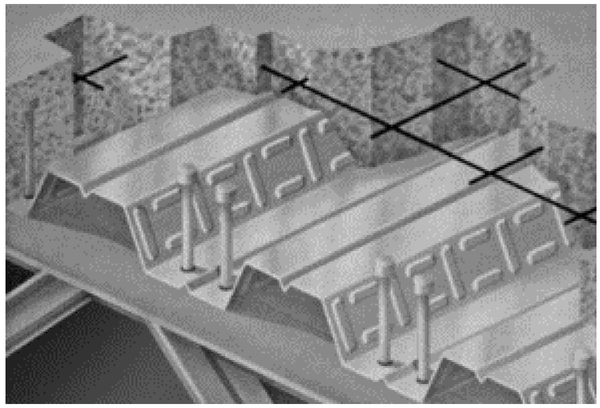


Table 14: Vulcraft 3VLI Metal Decking

Total Slab Depth	Deck Type	Maximum Unshored Clear Span		
		1 Span	**2 Span**	**3 Span**
5.50 (t=2.50) 39 psf	3VLI22	9'-8"	11'-7"	12'-2"
	3VLI20	11'-3"	13'-7"	14'-0"
	3VLI19	12'-8"	15'-0"	15'-1"
	3VLI18	13'-4"	15'-7"	15'-7"
	3VLI16	14'-0"	16'-4"	16'-5"

When building with concrete, the ponding effect requires an additional ten percent factor be added to the weight of the concrete. As wet concrete is placed, the metal decking and horizontal members deflect from the weight. To compensate for this deflection, more concrete is added in order to provide a level surface. An additional ten percent is added to account for the inconsistency in the concrete slab thickness.

The Mechanical, Electrical, and Plumbing (MEP) portion of the overall dead load of this academic building is estimated to be 10 psf, and the ceiling assembly is estimated to be 5 psf. The MEP and ceiling dead loads act on the structure above the floor they service. For example, the ceiling for the first floor acts on the structure of the second floor, and therefore, is listed as a dead load acting on Floor 2 in Table 15 below. The values of the concrete and metal decking, MEP systems, and ceiling construction are summed to a total uniform dead load of 56.3 psf (Table 15).

Table 15: Dead Loads (in psf)

Floor	Concrete & Decking	Concrete Ponding Effect	MEP	Ceiling	Total Dead Load
2	39	2.3	10	5	**56.3**
3	39	2.3	10	5	**56.3**
4	39	2.3	10	5	**56.3**
Roof	39	2.3	10	5	**56.3**

3.2.3 Snow Loads

The snow load provisions in ASCE 7-10 provide guidance for determining the magnitude of the snow loads based on the geographic location of the academic building, the type of building, and many other factors. The calculation of the snow load for this building is outlined below in Table 16:

Table 16: Snow Load Calculations

		Resource	Comments
1. Categorize Building			
Exposure Category	B	ASCE 7-10 Section 26.7.2	Category B refers to urban and suburban areas
Risk Category	III	IBC 2015 Table 1604.5	Category III refers to a “substantial hazard to human life” and public buildings with a occupancy load greater than 300
2. Determine Ground Snow Load and Factors			
Ground Snow Load (p_g)	55 psf	MA Building Code Table 1604.11	The town of Worcester is listed to have a Ground Snow Load of 55 psf.
Exposure Factor (C_e)	1.0	ASCE 7-10 Table 7-2	The Exposure Factor accounts for the surroundings of the roof and ranges from 0.7 to 1.2. The roof of a partially exposed building in Exposure Category B is 1.0.
Thermal Factor (C_t)	1.0	ASCE 7-10 Table 7-3	The Thermal Factor accounts for the interior temperature of the building which can affect the rate of snow melting and ranges from 0.85 to 1.3. Because this building will be heated, the thermal factor is 1.0.
Importance Factor (I_s)	1.10	ASCE 7-10 Table 1.5-2	The Importance Factor ranges from 0.80 to 1.20 depending on the Risk Category of the

			building. Because this building is Risk Category III, the factor is 1.10.
3. Calculate Snow Load			
$p_f = 0.7C_eC_tI_sp_g$	42.35 psf	ASCE 7-10 Equation 7.3-1	The total snow load based on the product of the Ground Snow Load and factors.

The building must first be categorized based on its exposure and risk level. The Exposure Category accounts for the surroundings of the building. For example, a building in a city will be impacted by weather differently than a building in an open plain. This building will be located on WPI's campus, which is in an urban area of Worcester, receiving a "B" Exposure Category. The Risk Category varies for the importance of the building in relation to human life. Buildings with high occupancies have a higher Risk Category than those used for storage with few human occupants. Buildings on college campuses with over 500 occupants are assigned a Risk Category of III. Therefore, this building is considered in Risk Category III because of the maximum occupancy load of 913.

In order to calculate the snow load, Equation 7.3-1 from ASCE 7-10, recreated as Equation 5 below, is used:

$$p_f = 0.7C_eC_tI_sp_g. \qquad \textit{Equation 5}$$

The first variable included in Equation 5 is the Ground Snow Load. This value varies by region and is provided in each state's building codes. In the *Massachusetts Building Code*, the city of Worcester is given a 55 psf ground snow load. The next variable, the Exposure Factor, is based on the Exposure Category of the building. The location of this building is partially exposed due to the slope of the hill and the surrounding buildings on three sides. These two considerations yield an Exposure Factor of 1.0 based on Table 7-2 in ASCE 7-10. Table 7-3 in ASCE 7-10 provides the various factors for different interior conditions of a building. Buildings that are maintained at a below freezing temperature require a larger snow load than a heated building, which is likely to melt some of the snow on the roof. Because this building will be occupied year round, it will be heated, yielding a thermal factor of 1.0. Lastly, the 1.10 Importance Factor acts as a safety factor for the calculation based on the Risk Category of the building. The product of all these parameters, in addition to the 0.7 coefficient, yields a flat roof snow load of 42.35 psf, as seen in Table 16.

The calculated snow load must be compared to the uniform live load from Table 1607.1 from the 2015 IBC to ensure that the maximum load is being considered. The 2015 IBC requires a live load of 20 psf for flat roofs that are not "occupiable." Therefore, the design load of this roof must be 42.35 psf.

3.3 Lateral Loads

Lateral loads act perpendicular to the structure of the building in a horizontal direction. Oftentimes, these lateral loads are the result of wind, seismic activity, or soil pressure. Wind and seismic loads act on the frame of the structure while soil pressure acts on the foundation. The discussion of the lateral loading due to soil pressure can be found in Section 3.10. This section will discuss the design of a lateral load resisting system to sustain the wind and seismic lateral loads and limit deflections.

3.3.1 Wind Loads

ASCE 7-10 outlines the calculation procedure for wind loads acting on a Main Wind-Force Resisting System (MWFRS). This procedure first defines all the characteristics and parameters of the building's location, geometry, and risk category. Each parameter and its value can be found below in Table 17.

Table 17: Wind Load Parameters

		Resource	**Comments**
Exposure Category	B	ASCE 7-10 Section 26.7.2	Category B refers to urban and suburban areas.
Risk Category	III	IBC 2015 Table 1604.5	Category III refers to a "substantial hazard to human life" and public buildings with an occupancy load greater than 300.
Basic Wind Speed (V)	135 mph	ASCE 7-10 Figure 26.5-1B	The town of Worcester falls between the 130 mph and 140 mph areas. Therefore, the mean wind speed was used.
Mean Roof Height (h)	64 ft		The mean roof height is the average of the highest point on the roof and the eave, or the height of a flat roof.
Enclosure Classification	Enclosed	ASCE 7-10 Section 26.2	This building does not satisfy either the "Open" or "Partially Enclosed" criteria, making it an "Enclosed" building (Appendix C)

Wind Directionality Factor (K_d)	0.85	ASCE 7-10 Table 26.6-1	The Wind Directionality Factor is 0.85 for all buildings.
Topographic Factor (K_{zt})	1	ASCE 7-10 Section 26.8	While this building is located on a hill, the hill is not isolated and the building is not isolated to the upper half of the hill. Therefore, the topography does not satisfy all five requirements for a non-one Topographic Factor.
Gust Factor (G)	0.85	ASCE 7-10 Section 26.9.4	This building is classified as a rigid structure, yielding a Gust Factor of 0.85, because the natural frequency is 1.2 by Equation 26.9-4.

ASCE 7-10 provides several different methods of analyzing the wind loads acting on a building based on these parameters. The geometry and height of this building allowed the use of the Simplified Directional Procedure as explained in ASCE 7-10 Chapter 27, Part 2. This method provides the values of wind pressure in tables based on the ratio of the sidewall to windward wall, L/b. Table 27.6-1 in ASCE 7-10 lists these wind pressures and can be used to interpolate the pressure values for this building based on the parameters and factors. This table yields the pressure acting on the base of the building and at the top of the building as seen below in Table 18.

Table 18: Wind Load on Walls

		Resource	Comments
L/B	1.51	ASCE 7-10 Table 27.6-1	The ratio of the sidewall to the windward wall.
Wind Load at Top (p_h)	36.99 psf	ASCE 7-10 Table 27.6-1	The wind pressure represents the interpolation of the wind pressure at the top of the building given the above criteria.
Wind Load at Base (p_o)	28.70 psf	ASCE 7-10 Table 27.6-1	The wind pressure represents the interpolation of the wind pressure at the base of the building given the above criteria.

As wind moves across a roof, it enacts a negative pressure, or suction, load on the roof surface. This causes negative pressures on all roof surfaces with varying severities depending on the slope of the roof. In addition, roofs are divided into zones as the pressure varies in different areas of the roof. A flat roof is divided into three zones, as shown below in Figure 16.

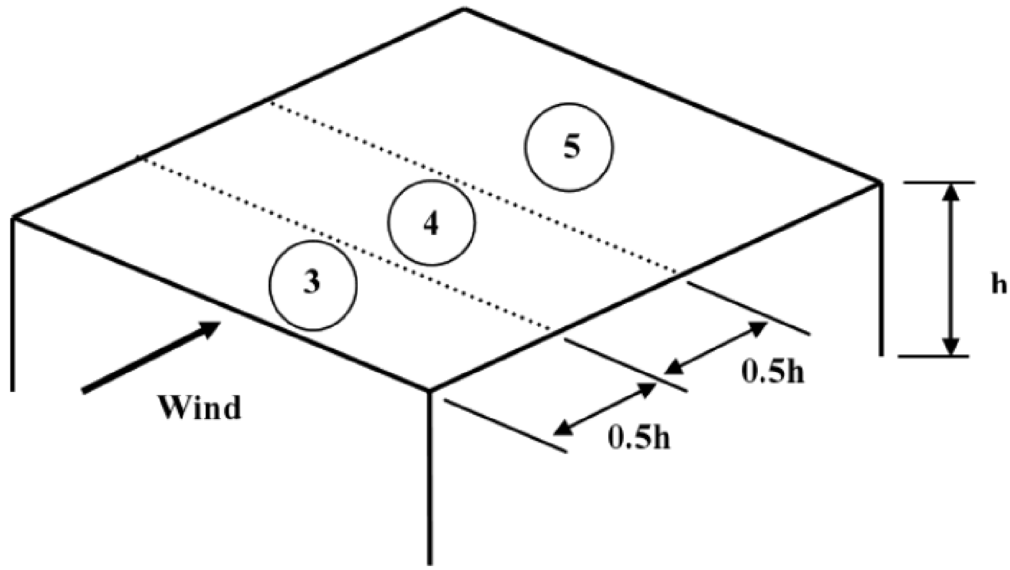


Figure 16: Roof Wind Zones
(from ASCE 7-10 Table 27.6-1)

Zone 3 has the greatest pressure due to the proximity of the wind force. Zone 4 has less pressure than Zone 3, and Zone 5 has the least pressure of the three zones. An Exposure Adjustment Factor is included to adjust wind pressure values for Exposure B or Exposure D buildings as the tables only include information for Exposure C buildings. This value can be multiplied by the wind pressures found in ASCE 7-10 Table 27.6-2 and listed below in Table 19.

Table 19: Wind Loads on Roof

		Resource	**Comments**
Exposure Adjustment Factor	0.756	ASCE 7-10 Table 27.6-2	The Exposure Adjustment Factor adjusts the tables for Exposure Categories other than Exposure C based on the building height.
Wind Load on Roof – Zone 3	-48.65 psf	ASCE 7-10 Table 27.6-2	This value is the wind load acting on Zone 3 of the roof.
Wind Load on Roof – Zone 4	-43.35 psf	ASCE 7-10 Table 27.6-2	This value is the wind load acting on Zone 4 of the roof.
Wind Load on Roof – Zone 5	-35.58 psf	ASCE 7-10 Table 27.6-2	This value is the wind load acting on Zone 5 of the roof.

The values influence both the structural design of the roof support system and the roof system design as the roofing membrane must be adhered well enough to resist these negative pressures.

3.3.2 Seismic Loads

Seismic loads occur when there is "earthquake-generated agitation to a building structure" that causes load displacements (Seismic load, 2014). The process to calculate the lateral loads resulting from seismic activity is summarized in the flowchart in Figure 17.

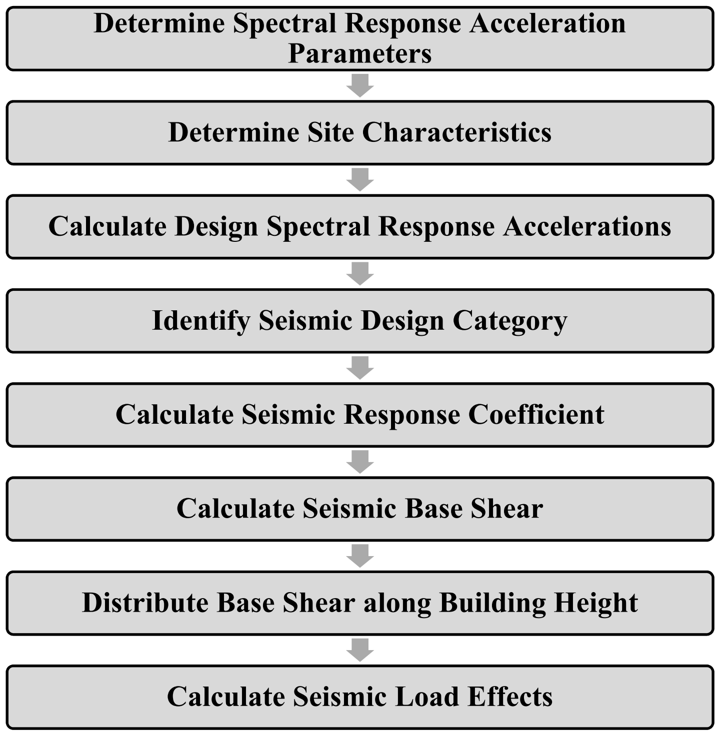


Figure 17: Seismic Load Calculation Procedure

The following table, Table 20, provides all the parameters needed to complete the seismic loading calculations.

Table 20: Seismic Calculation Parameters

		Resource	**Comments**
1. Determine S_S and S_1			
Spectral Response Acceleration Parameter at 0.2 seconds (S_S)	0.180g	USGS Report	S_S is the acceleration felt by a building over a short period. These values vary by location and can be found from maps in ASCE 7-10 or online through the USGS application.
Spectral Response Acceleration Parameter at 1 second (S_1)	0.066g	USGS Report	This spectral response acceleration parameter is for a 1-second period.

2. Determine Site Characteristics			
Site Class	D	ASCE 7-10 Section 20.1	The site classification accounts for the variety in soil type at different locations. The default Site Class is Class D when no information is provided.
Site Coefficient (F_a)	1.6	ASCE 7-10 Table 11.4-1	The Site Coefficient, F_a, is based on the Site Class and S_S. F_a ranges from 0.8 to 2.5 depending on the parameters.
Site Coefficient (F_v)	2.4	ASCE 7-10 Table 11.4-2	The Site Coefficient, F_v, is based on the Site Class and S_1. F_v ranges from 0.8 to 2.5.
3. Calculate Design Spectral Response Accelerations			
Design Spectral Response Acceleration at 0.2 seconds (S_{DS}) = 2/3(F_a)(S_S)	0.192	ASCE 7-10 Equation 11.4-3	S_{DS} provides the design value based on S_D.
Design Spectral Response Acceleration at 1 second (S_{D1}) = 2/3(F_v)(S_1)	0.106	ASCE 7-10 Equation 11.4-4	S_{D1} is the design value based on S_1.
4. Identify Seismic Design Category and Method			
Risk Category	III	IBC 2015 Table 1604.5	Category III refers to a "substantial hazard to human life" and public buildings with an occupancy load greater than 300.
Seismic Design Category (SDC)	B	ASCE 7-10 Table 11.6-1 and 11.6-2	The Seismic Design Category is based on the S_{DS} and S_{D1} and the Risk Category.
Method	ELF	CodeMaster	Any buildings in the Seismic Design Category B or C are allowed to use the Equivalent Lateral Force procedure (ELF.)

The Seismic Design Category dictates which method of analysis is required, either the Equivalent Lateral Force procedure or an intensive dynamic analysis. The Equivalent Lateral Force procedure allows a base shear force applied to the base of the building to be distributed along the height of the building. This procedure is outlined in ASCE 7-10 Section 12.8 and applied to this building as seen below in Table 21.

Table 21: Equivalent Lateral Force Procedure

5. Calculate Seismic Response Coefficient			
Earthquake Importance Factor (I_e)	1.25	ASCE 7-10 Table 1.5-2	All Risk Category III buildings are given an Earthquake Importance Factor of 1.25, which acts as a safety factor for the design.
Response Modification Coefficient (R)	3	ASCE 7-10 Table 12.2-1H	This coefficient varies depending on the type of structure within the building.
Effective Seismic Weight (W)	2679 kips	ASCE 7-10 Section 12.7.2	The Effective Seismic Weight includes the dead weight acting on the structure and 20% of the snow load. This value represents any dead load that could be acting on the structure during the time of seismic activity.
Seismic Response Coefficient (C_s) $C_S=\frac{S_{DS}}{R/I_e}$	0.08	ASCE 7-10 Equation 12.8-2	The Seismic Response Coefficient converts the seismic weight to the lateral force acting on the building.
6. Calculate Seismic Base Shear			
Seismic Base Shear (V) $Q_E=V=C_sW$	214.29 kip	ASCE 7-10 Equation 12.8-1	The Seismic Base Shear is the lateral load acting on the base of the structure during an earthquake.

The seismic base shear force acting on the base of the building must be distributed to each story of the building as seen below in Figure 18 where F_x is the force acting on each story, w_x is the effective seismic weight of each story, h_x is the height of each story, and V is the base shear force.

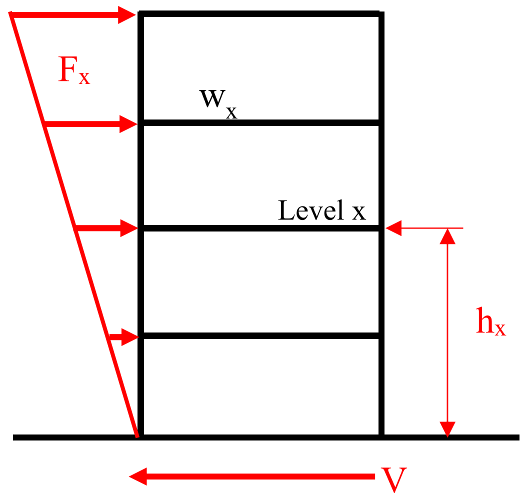


Figure 18: Distribution of Shear Force along Building Height

Equation 12.8-2 of ASCE 7-10, recreated below as Equation 6, provides the ratio of the base shear force, V, to the force acting on each floor:

$$C_{vx} = \frac{w_x h_x^k}{\sum_{i=1}^{n} w_i h_i^k} \qquad \textit{Equation 6}$$

In Equation 6, w_x is the effective seismic weight acting on floor x, h_x is the height of floor x, and k is based on the Approximate Fundamental Period of the building, as seen below in Figure 19.

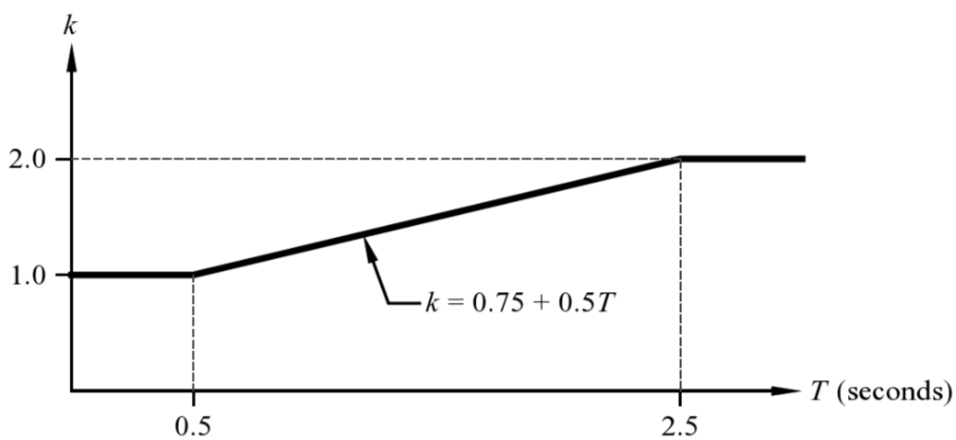


FIGURE C12.8-4 Variation of Exponent *k* with Period *T*

Figure 19: k in Relation to T
(from ASCE 7-10 Figure C12.8-4)

As seen above, the Approximate Fundamental Period (T) needs to be calculated to find k. The Approximate Fundamental Period is the product of the parameters C_t and h_n from ASCE 7-10 Equation 12.8-7 and Table 12.8-2. This yields a period of 0.45s, which is in the section of the variation where k equals 1.0. With k equal to 1.0, the distribution of the base shear is linear with the height of the building as drawn above in Figure 18. Using these values, the ratio between the base shear and force at each level, C_{vx}, can be calculated. This ratio can then be applied to the base shear force calculated above to yield the force acting on each floor as done in Table 22.

Table 22: Distributed Seismic Loads and Load Effects

7. Distribute Base Shear along Height of Building			
Approximate Fundamental Period (T_a) = $C_t h_n^x$	0.45 s	ASCE 7-10 Equation 12.8-7 and Table 12.8-2	The Approximate Fundamental Period can be calculated by $C_t h_n^x$ where C_t and x are found in Table 12.8-2 and h_n is the structural height of the building.
$C_{vx} = \frac{w_x h_x^k}{\sum_{i=1}^{n} w_i h_i^k}$		ASCE 7-10 Equation 12.8-12	Based on period being less than 0.5 s, the value of k is equal to 1.
C_{v2}	0.08		w_2 = 644 kips, h_2 = 13.08
C_{v3}	0.17		w_3 = 644 kips, h_3 = 27.67
C_{v4}	0.28		w_4 = 644 kips, h_4 = 45.00
C_{vR}	0.46		w_R = 747 kips, h_R = 64.00
$F_x = C_{vx}V$		ASCE 7-10 Equation 12.8-11	The lateral seismic force acting at each level is the product of C_{vx} and V.
F_2	17.51 kip		
F_3	37.05 kip		
F_4	60.25 kip		
F_R	99.47 kip		

Next, the shear base force must be included in the load combinations from ASCE 7-10 Section 12.4.2.3 to find the new design loads for the structure as seen in Table 23.

Table 23: Seismic Load Effects

8. Calculate Seismic Load Effects			
Redundancy Factor (ρ)	1.0	ASCE 7-10 Section 12.3.4	The Redundancy Factor is 1.0 for any structure with a SDC of B. This factor accounts for multiple paths that the loads could take through the structural system.
$(1.2+0.2S_{DS})D+\rho Q_E+L+0.2S$		ASCE 7-10 Section 12.4.2.3 #5	This load combination includes all the various loads acting on the structure to provide the maximum design load.
Factored Vertical Loads	336.40 psf		
Factored Horizontal Loads	214.29 kips		
$(0.9-0.2S_{DS})D+\rho Q_E$		ASCE 7-10 Section 12.4.2.3 #7	This load combination represents the scenario in which the seismic forces counter the dead load, producing an overturning or uplift of the structure.
Factored Vertical Loads	407.29 psf		
Factored Horizontal Loads	214.29 kips		
Maximum Vertical Design Load:	407.29 psf	See Above	The greater of the two load combinations is selected as the design load for the structure.
Maximum Horizontal Design Load:	214.29 kips		

The final step of these seismic calculations was to check the story drift with the allowable drift. Lateral loads cause the upper stories of a building to move horizontally while the base of the building does not move, as seen below in Figure 20.

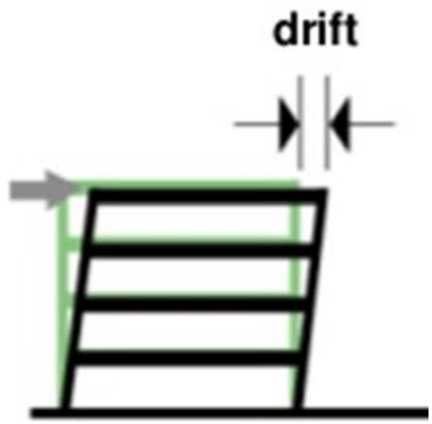


Figure 20: Story Drift

RISA-2D Structural Analysis software was used to calculate drift values. The structural model was recreated based on the framing sizes calculated for each member and the loads acting on those members (Figure 21).

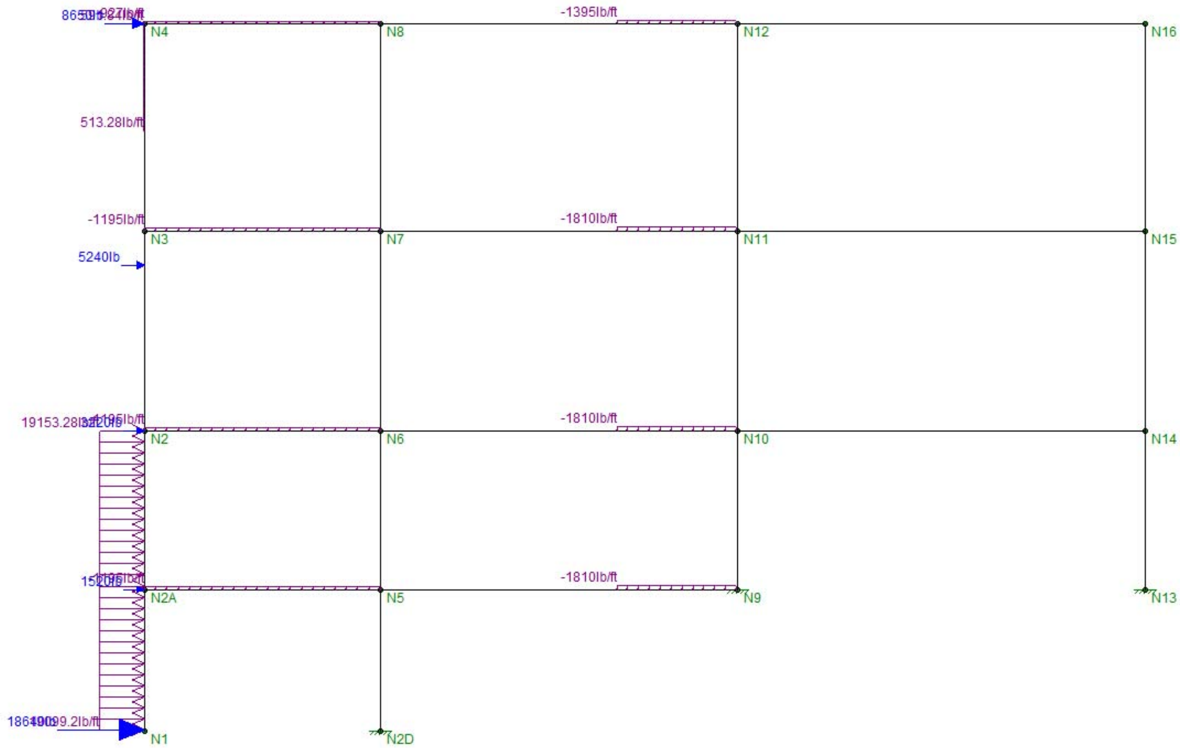


Figure 21: Frame 1 in RISA-2D

The story drift values from RISA represent the elastic deflection of the building. Inserting these values into Equation 7 with the values of C_d and I_e from ASCE 7-10 Table 12.2-1 and Table 1.5-2, respectively, yields the inelastic deflection, or the deflection that the building would not return from after the removal of the applied loads. C_d is the deflection amplification factor that adjusts the elastic deflection to inelastic deflection based on the material type. I_e is the same earthquake importance factor used in equations above to account for the building type and risk category.

$$\delta_x = \frac{C_d \delta_{xe}}{I_e} \qquad \textit{Equation 7}$$

These results were then compared to the allowable drift that is stated in ASCE 7-10 Table 12.12-1 and calculated in Table 24 below.

Table 24: Story Drift for Frame 1

Drift Control Requirement					ASCE 7-10 Equation 12.8-15 and Table 12.12-1	$C_d = 3$, $I_e = 1.25$
$\boldsymbol{\delta_3}$	0.668"	<	2.94”	OK		$\delta_{3e} = 0.835$
$\boldsymbol{\delta_4}$	1.605"	<	6.26”	OK		$\delta_{4e} = 2.01$”
$\boldsymbol{\delta_R}$	2.830"	<	10.92”	OK		$\delta_{Re} = 3.54$”

Based on these values, this building remains within the acceptable story drift limits with the seismic design loads of 355 psf. This indicates that the building is rigid enough to withstand the forces from seismic activity.

3.4 Rigid Frame

The structure of this building was designed as a rigid-frame system, where “a rigid frame in structural engineering is the load-resisting skeleton constructed with straight or curved members interconnected by mostly rigid connections which resist movements induced at the joints of members” (Rigid Frame, 2017). This design is based on the steel members being able to withstand all the loads acting on the system.

In order to confirm that this is the case and no additional lateral bracing is needed, a structural analysis was performed using RISA-2D. Different frame arrangements on various elevations of the building were selected as the critical frames on which to perform the analysis. Each elevation was selected with the exception of the frame along Column Line H. This area of the building contains a concrete wall for the second and third below-grade floors. Therefore, the frame would only consist of one story of steel members. The elevations along the entrance from the parking lot were not selected due to the small span of each frame along Column Line 4 and Column Line E. The locations of the three major frames can be found below in Figure 22.

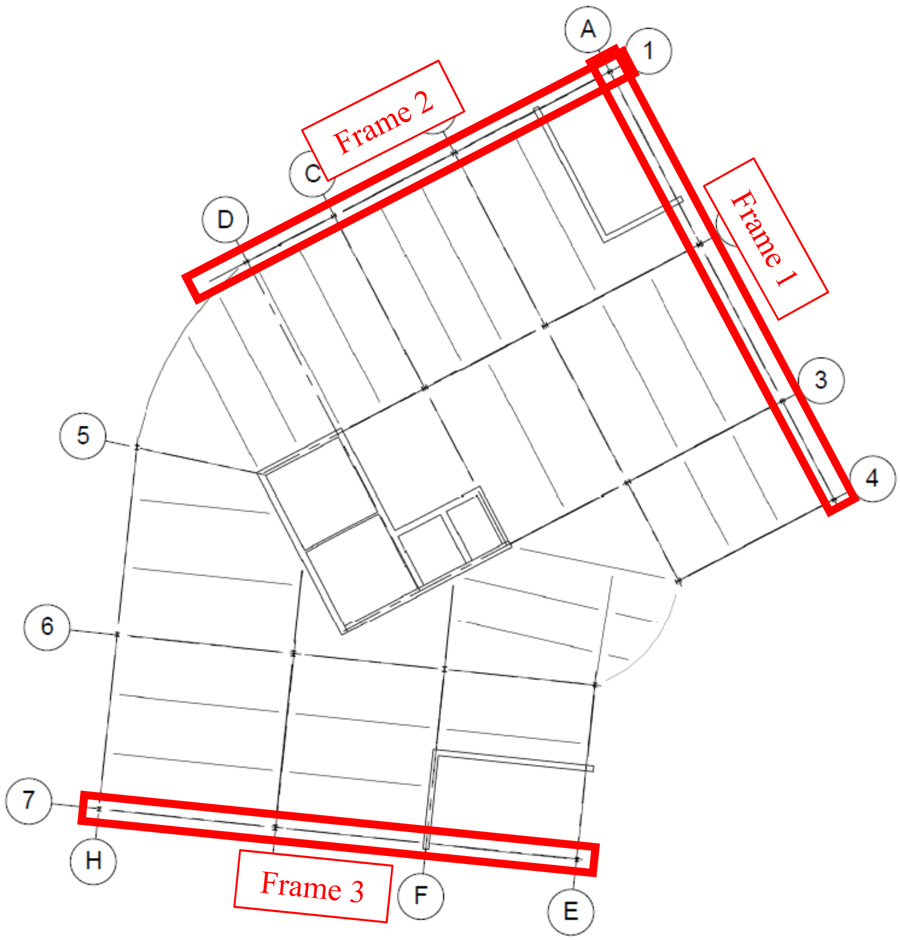


Figure 22: Frame Locations

After creating the model of Frame 2 in RISA-2D, the same procedures of adding loads to the frame, inputting load combinations, and calculating story drift were completed. The story drift for the second frame arrangement can be found below in Table 25 and Figure 23.

Table 25: Story Drift for Frame 2

Drift Control Requirement					ASCE 7-10	$C_d = 3$, $I_e = 1.25$
$\boldsymbol{\delta_3}$	0.773"	<	2.94”	OK	Equation 12.8-	$\delta_{3e} = 0.966$”
$\boldsymbol{\delta_4}$	1.20”	<	6.26”	OK	15 and	$\delta_{4e} = 1.50$”
$\boldsymbol{\delta_R}$	2.32”	<	10.92”	OK	Table 12.12-1	$\delta_{Re} = 2.90$”

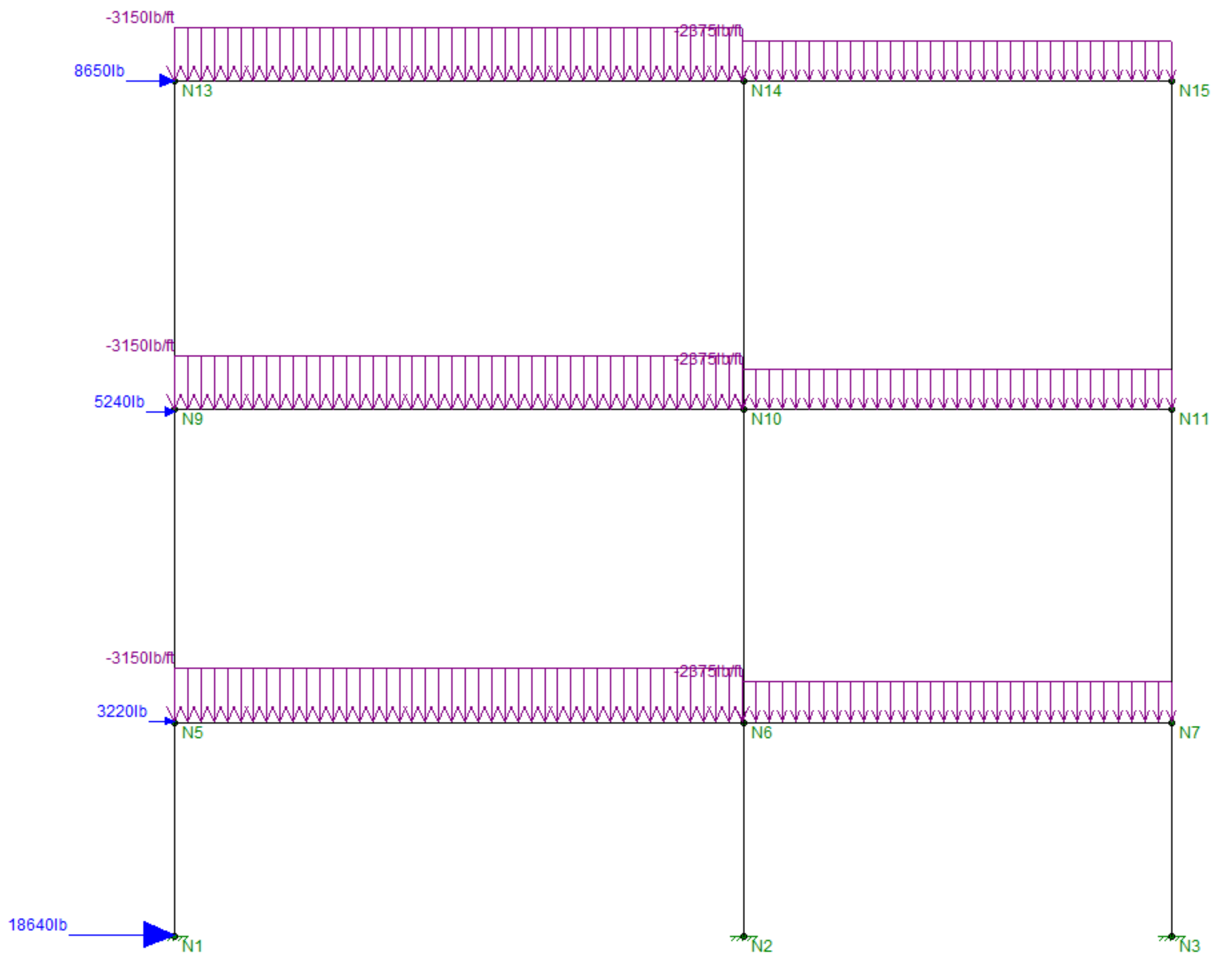


Figure 23: Frame 2 in RISA-2D

The story drift for Frame 3 can be found in Table 24 and Figure 24.

Table 26: Story Drift for Frame 3

Drift Control Requirement					ASCE 7-10	$C_d = 3$, $I_e = 1.25$
$\boldsymbol{\delta_3}$	0.98”	<	2.94”	OK	Equation 12.8-	$\delta_{3e} = 1.23$”
$\boldsymbol{\delta_4}$	1.46”	<	6.26”	OK	15 and	$\delta_{4e} = 1.83$”
$\boldsymbol{\delta_R}$	2.23”	<	10.92”	OK	Table 12.12-1	$\delta_{Re} = 2.79$”

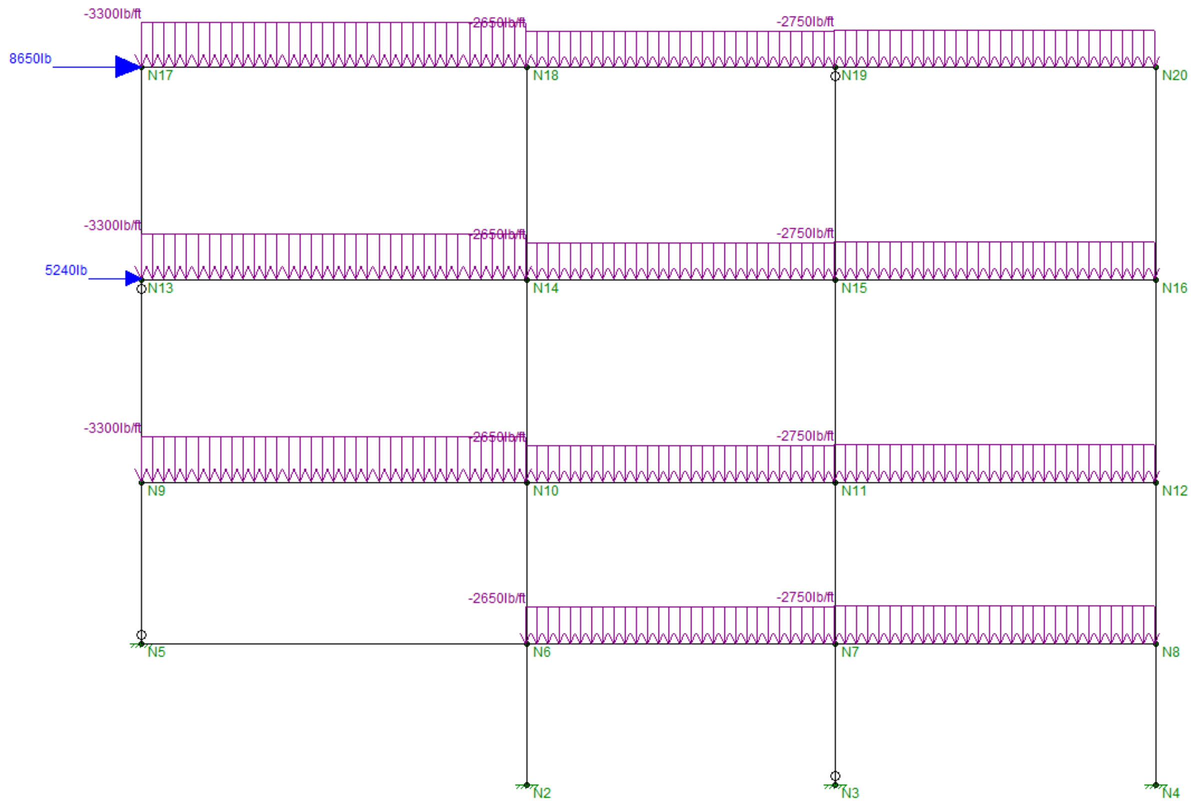


Figure 24: Frame 3 in RISA-2D

The simulation was conducted with the boundary conditions set to “Reaction” for the columns on the first level that would sit on footings or the foundation wall. The remaining joints were left without boundary conditions to simulate the steel-to-steel connections. Based on the analysis of the three frames, the story drift of the building frame is within allowable limits.

The second confirmation needed before deciding against the use of additional lateral bracing is confirming the framing members are able to withstand the lateral forces. Using the AISC load combinations, the new critical load was determined. The critical load was most often one of the two following load combinations listed below in Equation 8 and Equation 9.

$$1.2D + 1.6L + 0.8W \quad \text{(Equation 8)}$$

$$1.2D + 1.0E + 0.5L \quad \text{(Equation 9)}$$

Each member could then be checked with this new critical load to ensure it remained within the required section modulus for the selected member size. Of all the beams and girders, one girder, BC2, was found to be inadequate. This member was originally sized as a W24x68. The new critical load can be supported by a W30x99 and both columns B2 and C2 can sustain this additional weight from the member. Columns in a rigid frame must be investigated to confirm the member sizes are appropriate to withstand the combined bending and axial compression, including second-order effects. Appendix 8 of the *AISC Steel Manual* outlines the steps to perform this analysis. While not completed in this project, the column sizes would need to be confirmed using this Approximate Second-Order Elastic Analysis prior to construction.

The structure meets the lateral force requirements due to two major factors, the spans between members and the structural concrete walls. As the spans between columns are all less than 35 feet, the lateral movement of the frame is small. This design approach provided enough structural stability for the story drifts to be well within the allowable limits. Secondly, there are concrete walls at two corners of the building, in the center of the building, and along the west side of the building. These solid concrete walls provide the stability needed to prevent the steel frame from excess lateral movement. The structural steel design contained enough inherent lateral bracing in the rigid frame to account for both the gravity and lateral loads, eliminating the need for additional lateral bracing.

3.5 Framing Considerations

Two structural systems within every building share the same members but are primarily there to resist different loads. The gravity framing system resists the loads in the direction of gravity while the lateral framing system resists the load of lateral forces and stops the building from building sway. The design of the structural framing needs to consider a load path for transferring the supported forces into the ground. The load path within a steel structure allows the load to transfer into the floor, which then moves into the beams, followed by the girders, which then transfer the load to the columns. From the columns, the loads pass into the footing, which then transfers the loads into the soil.

The AISC Specification provides two allowable methods for designing structural members and their connections. These two methods are the Load and Resistance Design (LRFD) and Allowable Strength Design (ASD). Both methods share a common goal of obtaining a numerical margin between resistance and load that will result in a small probability of unacceptable steel response. The ASD approach involves the use a single safety factor that is used with any load combination. From this safety factor, an allowable stress is determined for the design of a specific member. Historically, stresses were evaluated and compared, but currently they are analyzed through strength factors, such as forces and moments. The service loads are then used to determine the actual stress, which must coincide with the allowable stress. There are many different types of service loads to resist, such as dead loads, live loads, snow loads, etc. Since the total service load is relevant to the design of the structural member, the required strength is always the same for the varying load combinations. Alternatively, while using the LRFD approach, the required strength may vary. The service loads are then multiplied by code specified factors to form factored loads and load combinations for the LRFD design.

Historically, the ASD method has delivered safe and reliable steel and composite structures. However, the method does not consider inconsistency of various load effects (live load, dead load, snow load, etc.) and resistances (shear capacity, bending, cracks, etc.). For this reason, the design team chose to design with the LRFD approach. With the LRFD approach, more consistent reliability is achieved during the structural steel design process and, in many cases, a more cost-effective steel structure result. The main advantage of LRFD is that, by applying a statistical analysis to the various values of strengths and loads, a consistent factor of safety may be achieved for all types of steel structures. In order to properly size the required horizontal members, the design team followed the AISC guidelines for LRFD as outlined in the Steel Manual.

3.6 Horizontal Member Calculations

The structural design consists of three types of horizontal members: girders, beams, and joists. The girders are the horizontal members running along the major axis between columns. These typically span the greatest distance of the horizontal members and support the joists, making them the largest members. The beams bear on columns as well but span the minor axis, often smaller distances than the girders. The joists are typically the smallest members as they span the distance between girders on the minor axis and bear on the girders. The difference between a girder, beam, and joist is demonstrated below in Figure 25.

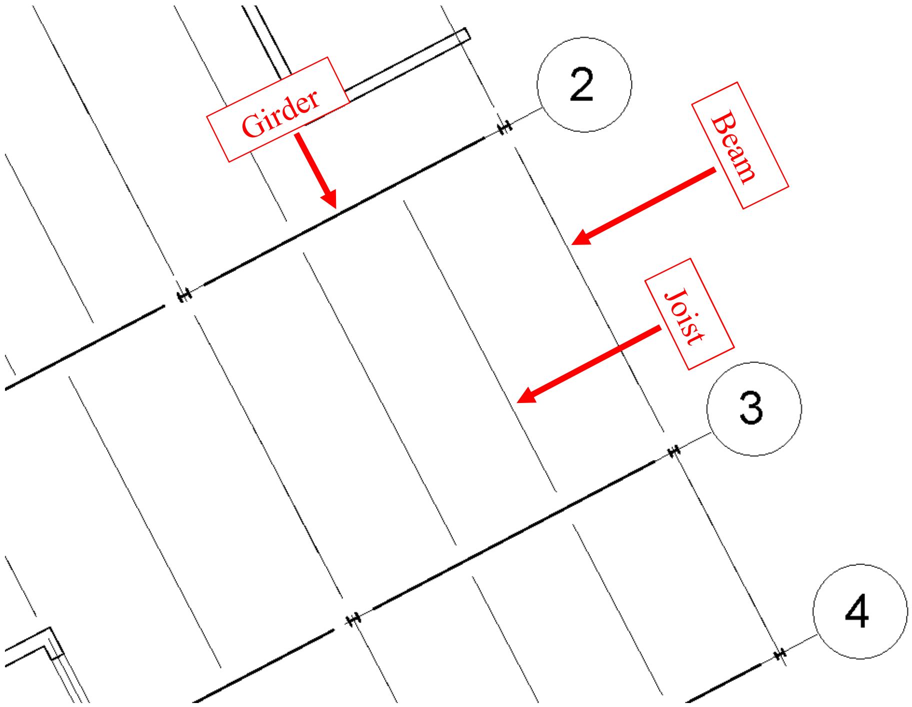


Figure 25: Girder, Beam, and Joist

The first step is to determine the length and tributary width of each joist. The tributary width is defined as the distance to each side of the member that it must support, x and y in Figure 26. Oftentimes, it is half the distance between the joist or girder and the members on either side. For example, in Figure 26, the tributary area of Member B is half the area between Member A and Member B and half the area between Member B and Member C. The joist must be able to support the dead and live load of the floor for that specified width. Once this value is calculated, it is multiplied by the length of the member (L) to find the tributary area as shaded below. This area is the total area that the joist is responsible for supporting.

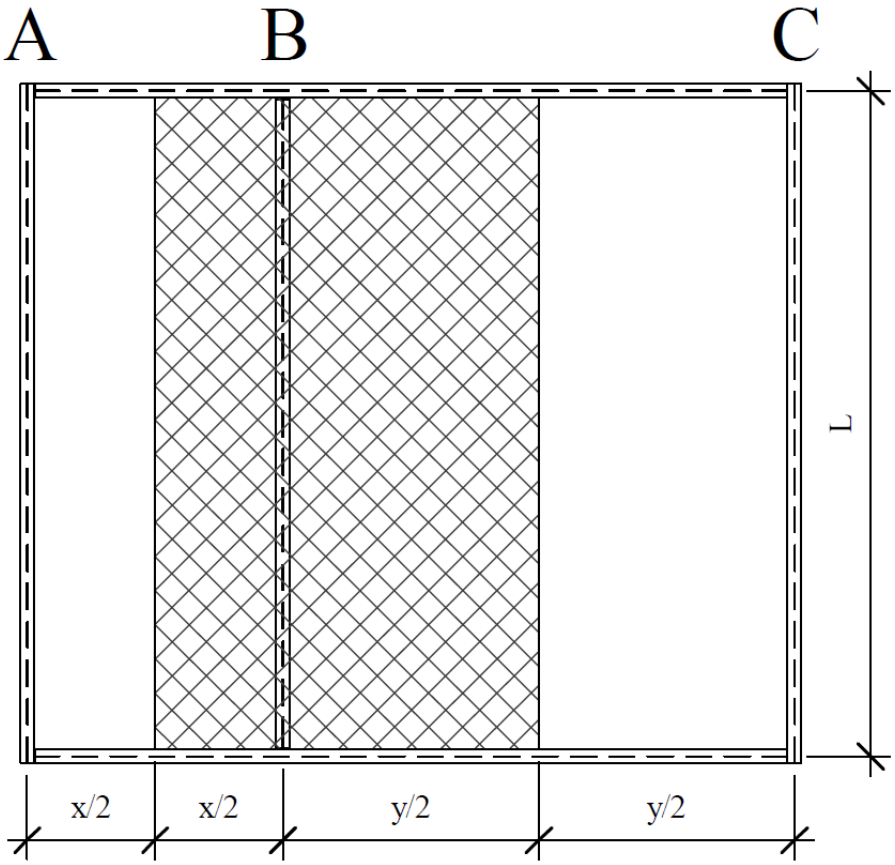


Figure 26: Tributary Area of Member B

The tributary area can be calculated using Equation 10.

$$\text{Tributary Area} = \left(\frac{x}{2} + \frac{y}{2}\right) \text{ x L}$$ *Equation 10*

This tributary area is then multiplied by the pounds per square foot of the live loads and dead loads from the supported floor and deck to calculate the total number of pounds bearing on the member. This value, in pounds, is then divided by the length of the member to obtain units of pounds per linear foot (plf).

The next step is analyzing the various load combinations to determine the critical load. Load combinations are used to account for the variety of loads that may be acting on a system at a given time. The various combinations represent different scenarios by multiplying factors by the different types of loads (dead, live, wind, seismic, etc.). The two load combinations used for these horizontal member calculations are below in Equation 11 and Equation 12.

$$1.4D \qquad \textit{Equation 11}$$

$$1.2D+1.6L \qquad \textit{Equation 12}$$

These equations are used based on the fact that horizontal members mainly support the dead and live loads of the floor above. The larger of these two values becomes the critical design load for which the member must be sized. Once the design load for the member has been determined, the moment can be calculated from Equation 13.

$$M_u=\frac{wL^2}{8} \qquad \textit{Equation 13}$$

In Equation 13, *w* is the load in pounds per foot and *L* is the length of the member. This yields the required moment capacity that can then be used in Equation 14, to determine the minimum required section modulus (Z).

$$M_u= \Phi F_y Z \qquad \textit{Equation 14}$$

Φ represents the resistance factor, which is assigned as 0.90 in LRFD calculations to account for uncertainties in the loads and materials, and F_y is the yield strength of steel. In this case, A992 steel is used, which has a yield strength of 50 kips per square inch (ksi). These values provide the minimum allowable section modulus. AISC Table 3-2 provides data on all the possible W-shapes organized by section modulus. For each calculation, the least weight option was selected with the section modulus greater than the required value calculated. Once the member was selected, the load, moment, and section modulus were revised and recalculated to account for the weight of the member. If the revised section modulus was less than the section modulus of the member, then the selection was acceptable. The final step to ensure the proper selection of the member was to confirm that it meets the minimum deflection requirements. 2015 IBC Table 1604.3 specifies that the deflection of a member is less than the length of that member divided by 360. The deflection of the member can be calculated with Equation 14, where *w* is the revised load, *L* is the length of the member, *E* is the modulus of elasticity of the steel, and *I* is the moment of inertia of the member.

$$\Delta = \frac{5wL^4}{386EI}<\frac{L}{360} \qquad \textit{Equation 15}$$

The modulus of elasticity of A992 steel is 29×10^6 pounds per square inch (psi), and the moment of inertia is listed in AISC Table 3-2. If this deflection, Δ, is less than the length of the member divided by 360, then the member is acceptable. If not, a larger member must be selected in order to satisfy the deflection limit, and the process must be repeated. A sample of these calculations can be found below in Table 27.

Table 27: Horizontal Member Sizing Calculation

Member Identification						**Comments:**
Level	4					
Bay	AB					
Start/End	2/3					
1. Calculate Tributary Area						
Length	31	ft				
Tributary Width	10.58	ft				
Tributary Area	328	ft				Equation 10
2. Calculate Design Loads						
Live Load (L)	100	psf	=	1058	plf	Section 3.2.1
Dead Load (D)	58.3	psf	=	617	plf	Section 3.2.2
1.4D	81.62	psf		864	plf	
1.2D+1.6L	229.96	psf		2435	plf	
3. Calculate Required Moment and Section Modulus						
Moment (M_u)	292.35	ft-kip				Equation 13
Section Modulus (Z_x)	77.96	in^3				Equation 14
4. Select Member from AISC Table 3-2 that Meets Required M_u and Z_x						
Member	W21x55					
Section Modulus (Z)	126	in^3				
Moment of Inertia (I)	140	in^4				
5. Revise Calculated Values to Include Self-Weight of Selected Member						
Revised Load	2500	plf				
Revised M_u	300.28	ft-kip				
Revised Z_x	80.08	in^3	<	Z	OK	
6. Check Deflection Limit						
Live Load Deflection Limit (Δ_{allow})	1.03	in				Equation 15
Live Load Deflection (Δ_{LL})	0.67	in	<	Δ_{allow}	OK	L/360 by 2015 IBC Table 1604.3

The beams were sized following the same procedure. The only difference with the beams is that they bear on a column instead of bearing on a girder.

At the completion of the member selection process, there were fifteen various sizes ranging from W12x16 to W30x99. In order to limit the variety of sizes needed, various options were analyzed to simplify the member selection. The following five members were selected: W14x30, W18x40, W21x55, W24x68, and W30x99 based on the frequency of members, similarity between sizes, and weight efficiency. For example, instead of increasing all the W21 members to W21x68, the W21x44 and W21x50 were increased to a W21x55, and the W21x62 and W21x68 were increased to a W24x68. Eleven W21x55 would need to be increased to W21x68 members while there are only five W21x62 and two W21x68 members if the W21x55 size is selected. Using this decision-making model and calculations, the following changes (Table 28) were made to the member sizes in order to simplify fabrication and procurement processes and reduce the cost of steel.

Table 28: Horizontal Member Sizing Optimization

W12x16	2	→	14x30
W14x30	5		
Total	**7**	**W14x30**	
W16x31	1	→	W18x40
W16x40	1	→	W18x40
W18x35	6	→	W18x40
W18x40	2		
Total	**10**	**W18x40**	
W21x44	6	→	W21x55
W21x50	4	→	W21x55
W21x55	11		
Total	**21**	**W21x55**	
W21x62	5	→	W24x68
W21x68	2	→	W24x68
W24x62	2	→	W24x68
W24x68	4		
Total	**13**	**W24x68**	
W27x84	1	→	W30x99
W30x99	2		
Total	**3**	**W30x99**	

3.7 Curved Beam

The main design feature of the southeast entrance is the curved curtain wall along the center of the two large curtain walls spanning all floors of the building. This curved element provides the smooth transition between the two wings of the building. The location of the curved wall can be seen below in Figure 27.

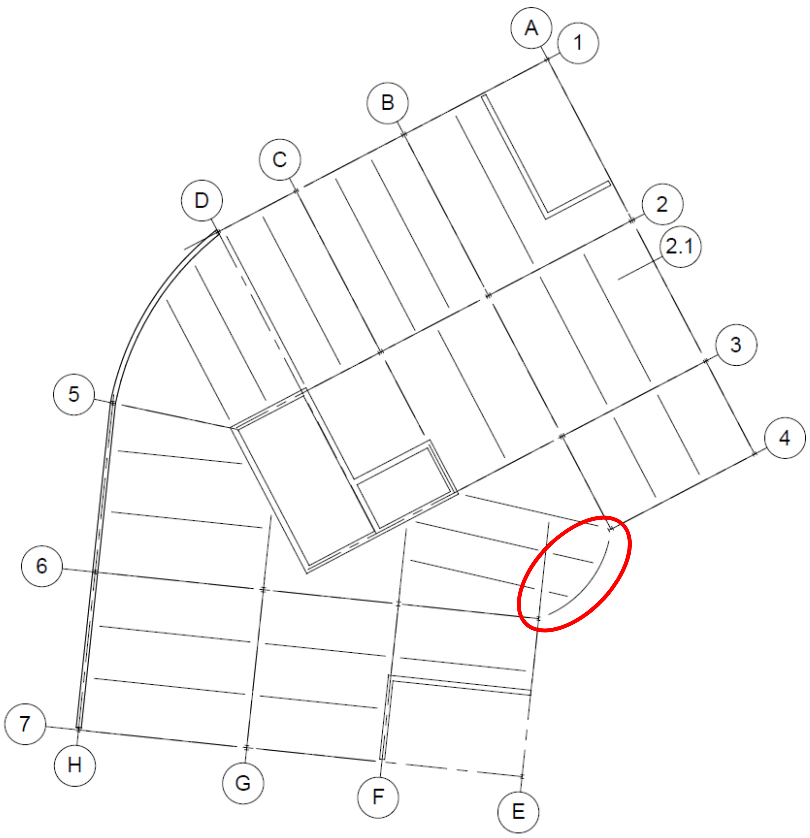


Figure 27: Curved Beam Location

To properly support the curved curtain wall, a custom steel girder was needed. Steel members can be curved by specialty contractors using rollers and heat to curve members into the proper shape. To get a rough estimate of the size needed for this curved girder, it was sized as if it was a straight member following the procedure seen in Table 27. The only difference in the calculation was the determination of the tributary area. Instead of multiplying the tributary width by the length of the member, the irregular area between the curved beam and half the distance to the next nearest horizontal member was calculated. This calculation guided the selection of a W21x55 member, an estimate accurate enough to size the columns and other affected components. The complete calculation is in Appendix D. However, this member would need to be subcontracted to a specialty contractor for a full analysis.

3.8 Column Calculations

The initial steps of selecting the appropriate column size are similar to those for the horizontal members. The first step is to determine the tributary area by taking half the distance to the next column on each side of the column in question. Then, the tributary area of the column can be calculated and used to find the dead load, live load, and snow load acting on each column. The other dimension needed is the unbraced height of each column, or the height that a column spans without any lateral bracing. Because each floor system acts as a lateral brace, the height is equivalent to the height between floors. For the bottom floors, this height is 13'-10" and for the top floors, it is 18'-0". To reduce the number of steel members needed, columns should span two floors. This would reduce the number of necessary columns by half. It was decided that the columns would span two floors with a splice three feet above the third floor, as seen below in Figure 28, to make the connection easier for the ironworkers. Similar to the girders, the dead loads from all horizontal members bearing on the column must be included as well. These can be determined by multiplying the weight of each member by half the length as that is the portion of the load each column must support. The major difference between the loads acting on a vertical member is that the loads from each floor are additive, meaning the bottom column must be able to support the weight of the second, third, and fourth floors and the roof.

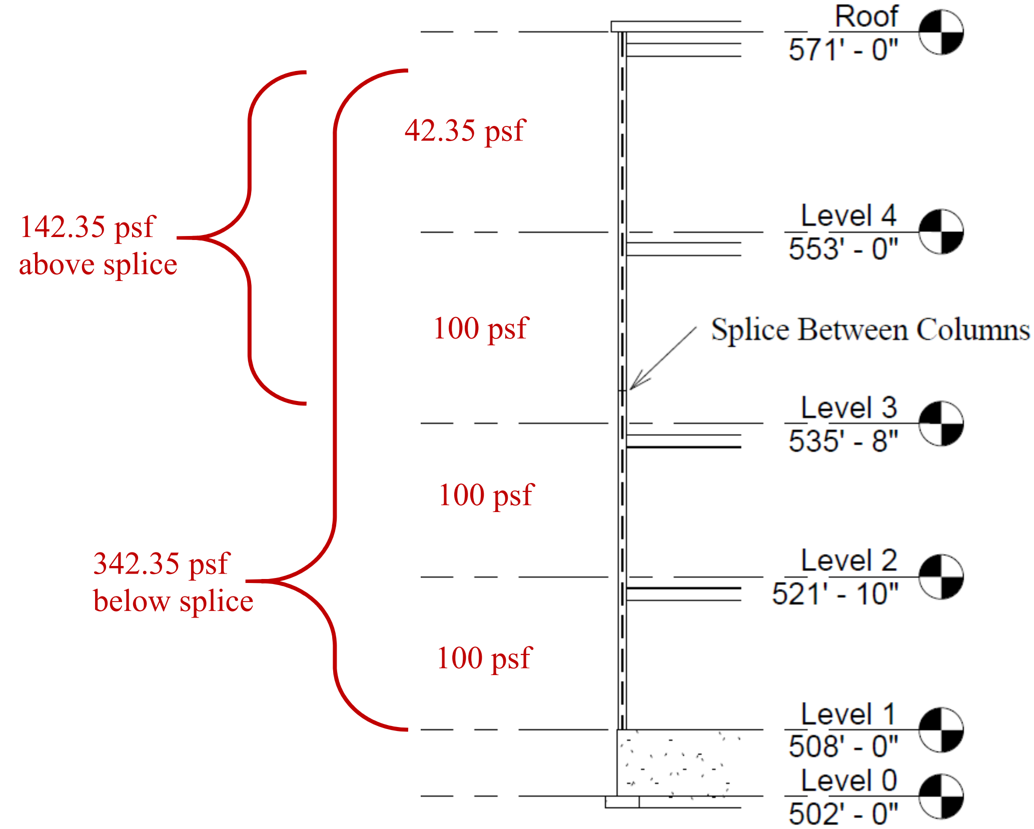


Figure 28: Column Splice Location

Another minor difference is the incorporation of the roof load in the load combination equations for three various options listed below as Equation 16, Equation 17, and Equation 18.

$$1.4D \quad \textit{Equation 16}$$

$$1.2D + 1.6L + 0.5(L_r \text{ or } S \text{ or } R) \quad \textit{Equation 17}$$

$$1.2D + 1.6(L_r \text{ or } S \text{ or } R) + L \quad \textit{Equation 18}$$

These load combinations, as discussed above in Section 3.6, represent the various gravity loads that may be acting on the system at a given time. The column load combinations include the roof live load (L_r), the snow load (S), and the roof load (R). These values must be considered as the gravity loads are transferred through the entire column and onto the column below. Therefore, all columns must be able to support the roof load in addition to the dead and live loads of all overlying floors. The sum of these loads provides the minimum load capacity that the selected member must have.

Next, using AISC Table 4-1, various options were selected for W-shapes with capacities exceeding the required capacity calculated from the factored loads and load combinations. One member from the W14, W12, W10, and W8 shapes were selected where applicable. Based on the information in Table 4-1, ΦP_n could be calculated to confirm that it exceeded ΦP_u, the design load. Then, the option with the lowest r_x/r_y ratio was selected. The variables r_x and r_y are the radii of gyration along the x-axis and the y-axis. Selecting the lowest ratio typically provides the most stable column option as it reduces the discrepancy between the strong and weak axis. The complete calculation procedure is outlined in Table 29.

Table 29: Column Sizing Calculation

Member Identification						**Comments:**
Level	Above Splice					
Bay	G8					
1. Calculate Tributary Area						
Tributary Length	16.50	ft				
Tributary Width	13.75	ft				
Tributary Area	227	ft^2				Equation 10
2. Calculate Design Loads						
Live Load (L)	250	psf	=	56.7	kips	
Dead Load (D)				39.2	kips	
Snow/Roof Load	42.35	psf	=	10.2	kips	
1.4D				54.8	kips	
$1.2D + 1.6L + 0.5(L_r$ or S or R)				142.8	kips	
$1.2D + 1.6(L_r$ or S or R) + L				120.0	kips	
3. Calculate Critical Load						
Critical Load (P_u)				142.8	kips	

4. Compare Members from AISC Table 4-1 with Required Critical Design Load									
Member	r_y	r_x/r_y	A_g	r_x	KL/r_y	F_e	F_{cr}	P_n	ΦP_n
W14x48	1.91	3.06	14.1	5.84	113.09	22.36	19.61	276.48	248.83
W12x40	1.94	2.64	11.7	5.12	111.34	23.06	20.18	236.11	212.50
W10x33	1.94	2.16	9.71	4.19	111.34	23.06	20.18	195.95	176.35
W8x31	2.02	1.72	9.13	3.47	106.93	25.01	21.65	197.69	177.92

5. Select Member with the Lowest r_x/r_y Value						
Column Selection	W8x31					

After all the columns were sized, there were seven different sizes needed. Again, the variety of column sizes was narrowed down to four sizes: W8x31, W8x48, W10x49, and W10x68 as seen below in Table 30.

Table 30: Above-Splice Column Sizing Optimization

W8x31	7		
Total	**7**	**W8x31**	
W8x35	1	→	W8x48
W8x48	3		
Total	**4**	**W8x48**	
W10x49	5		
Total	**5**	**W10x49**	
W10x54	1	→	W10x68
W10x60	1	→	W10x68
W10x68	1		
Total	**3**	**W10x68**	

Following these same steps, the columns below the splice were calculated with the additional weight of the floors and column above it. Due to the loads of the additional floors supported, the columns below the splice require larger members. The members were selected for the bottom columns: W8x31, W8x48, W10x49, W10x68, and W14x90 as show in Table 31.

Table 31: Below-Splice Column Sizing Optimization

W8x31	2		
Total	**2**	**W8x31**	
W8x35	2	→	W8x48
W8x48	1		
Total	**3**	**W8x48**	
W10x49	3		
Total	**3**	**W10x49**	
W10x54	2	→	W10x68
W10x60	1	→	W10x68
W10x68	1		
Total	**5**	**W10x68**	
W14x90	3		W14x90
Total	**3**	**W14x90**	

Once all the columns were sized for the appropriate gravity loads, the lateral loads were applied using the following load combinations listed as Equation 19, Equation 20 and Equation 21.

$$1.2D + 1.6W + 0.5L + 0.5(L_r \text{ or } S \text{ or } R) \quad \textit{Equation 19}$$

$$1.2D \pm 1.0E + 0.5L + 0.2S \quad \textit{Equation 20}$$

$$0.9D \pm (1.6W \text{ or } 1.0E) \quad \textit{Equation 21}$$

The columns that did not satisfy all load combinations were resized to members that could support all the gravity and lateral loads. The final column sizes can be found in Sheets S101-105 in Appendix Q.

3.9 Bridge Structure

The bridge between Kaven Hall and this AREN building is one of the major design components of this project. The bridge will allow for handicap accessibility into Kaven Hall and will provide for more collaboration between the AREN and CEE programs. In order to properly design this elevated walkway, the same process as described in Sections 3.6 and 3.8 was followed to size the steel members. The live load was selected as 60 psf as required by the 2015 IBC Table 1607.1 for “Walkways and elevated platforms.” The same calculation was performed to size each member of the structure, resulting in W14x30 beams and girders and W8x31 columns as seen in Table 32 and Table 33.

Table 32: Horizontal Bridge Members

1. Calculate Tributary Area						**Comments:**
Length	30	ft				
Tributary Width	5	ft				
Tributary Area	150	ft				Equation 10
2. Calculate Design Loads						
Live Load (L)	60	psf	=	300	plf	Section 3.2.1
Dead Load (D)	58.3	psf	=	292	plf	Section 3.2.2
1.4D	81.62	psf		408.1	plf	
1.2D+1.6L	165.96	psf		829.8	plf	
3. Calculate Required Moment and Section Modulus						
Moment (M_u)	93.35	ft-kip				Equation 13
Section Modulus (Z_x)	24.89	in^3				Equation 14
4. Select Member from AISC Table 3-2 that Meets Required M_u and Z_x						
Member	W14x30					
Section Modulus (Z)	47	in^3				
Moment of Inertia (I)	291	in^4				
5. Revise Calculated Values to Include Self-Weight of Selected Member						

Revised Load	865.80	plf				
Revised M_u	97.40	ft-kip				
Revised Z_x	25.97	in^3	<	Z	OK	
6. Check Deflection Limit						
Live Load Deflection Limit (Δ_{allow})	1.000	in				Equation 15
Live Load Deflection (Δ_{LL})	0.648	in	<	Δ_{allow}	OK	L/360 by 2015 IBC Table 1604.3

Table 33: Bridge Columns

1. Calculate Tributary Area									**Comments:**
Tributary Length	5.00	ft							
Tributary Width	15.00	ft							
Tributary Area	75.00	ft^2							Equation 10
2. Calculate Design Loads									
Live Load (L)	60	psf	=	4.500	kips				
Dead Load (D)				9.345	kips				
Snow/Roof Load	42.35	psf	=	3.375	kips				
1.4D				13.08	kips				
1.2D + 1.6L + 0.5(L_r or S or R)				23.81	kips				
1.2D + 1.6(L_r or S or R) + L				19.09	kips				
3. Calculate Critical Load									
Critical Load (P_u)	23.81	kips							
Critical Design Load (ΦP_u)	21.43	kips							
4. Compare Members from AISC Table 4-1 with Required Critical Design Load									
Member	r_y	r_x/r_y	A_g	r_x	KL/r_y	F_e	F_{cr}	P_n	ΦP_n
W8x31	2.02	1.72	9.13	3.47	213.86	6.25	1.76	16.06	14.45
5. Select Member with the Lowest r_x/r_y Value									
Column Selection	W8x31								

3.10 Foundation

Without a proper foundation, the loads on the structure of the building cannot be properly transferred into the ground. Oftentimes, the foundation of a commercial building consists of concrete walls with a strip footing to distribute the load over a greater surface area. In addition to supporting the vertical loads from the building above, the foundation wall in this project acts as a retaining wall to resist the lateral loads from the adjacent soil. The loads acting on the foundation wall can be seen below in Figure 29.

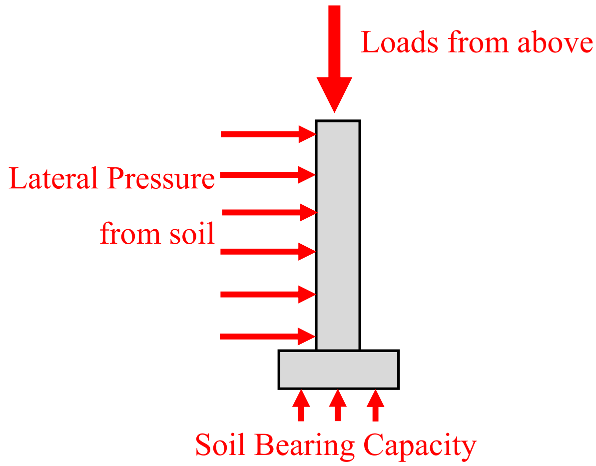


Figure 29: Loads Acting on Foundation Wall

The foundation of this building can be separated into the upper foundation for the three-story section of the building and the lower foundation for the four-story section of the building, as seen below in Figure 30.

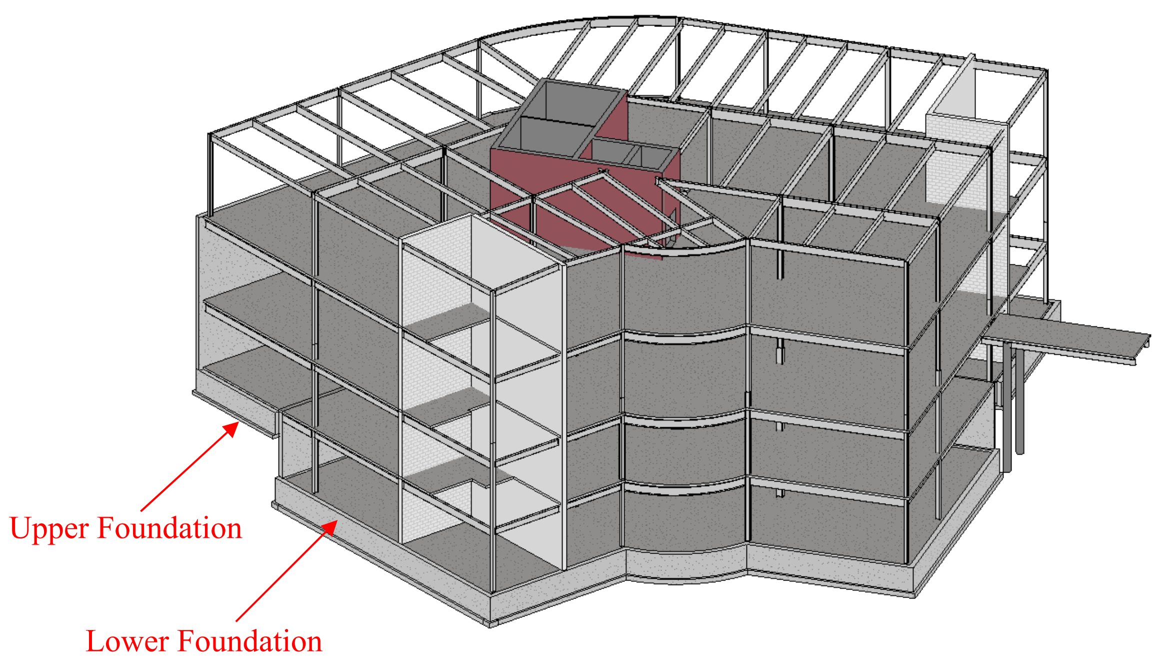


Figure 30: Upper and Lower Foundations

Section 1807.1.6 of the 2015 IBC states that "foundation walls that are laterally supported at the top and bottom" can be designed using the prescriptive method outlined in the same section. This method simplifies the process of designing a foundation by providing guidelines and tables that limit the calculations. The first floor of this building contains occupied space with a concrete slab at both the base of the floor and at the top of the floor. Therefore, this prescriptive method can be used in the design of the foundation.

The first major component of the foundation design is the soil classification. The properties of the soil determine the bearing capacity of the ground beneath the foundation and the lateral earth pressure acting on the foundation. Based on analysis during the construction of the adjacent Fuller Laboratories in 1988 and other buildings on campus, the soil beneath this building is glacial till. Glacial till is mostly composed of clay, sand, and gravel, the "SM" or "ML" classification in Table 3.2-1 of the ASCE 7-10. The 2015 IBC provides a 45 psf per foot of depth lateral pressure for both of these classifications. However, ASCE 7-10 indicates a 45 psf per foot of depth lateral pressure for the "SM" classification and 85 psf per foot of depth for the "ML" classification. For a more conservative design, the ASCE 7-10 design lateral soil load of 85 psf was used to determine the thickness of the foundation. The design load must first be converted into pounds per square inch (psi) to yield 12,240 psi per foot of wall depth as completed in Equation 22.

$$\frac{85\text{ psf}}{\text{ft wall depth}} \times \frac{144\text{ si}}{1\text{ sf}} = \frac{12{,}240\text{ psi}}{\text{ft wall depth}} \qquad \textit{Equation 22}$$

This value can be compared to those in Table 1807-1 of the *2015 International Building Code Illustrated Handbook* to determine that the foundation wall must be at least 7.5" thick. However, by Section 1807.1.6.1 of the 2015 IBC, the foundation wall must be as thick as the wall it is supporting. The exterior walls of this building include a 4" thick brick veneer and 2" air space that do not put any load on the foundation wall as the brick veneer is attached to the steel structure. Therefore, the thickness of the foundation wall is only required to be 10.25" thick, as shown in Figure 31, in order to comply with the 2015 IBC. However, in order to follow the standard foundation sizes, this thickness was increased to the next nominal thickness of 12". This value was compared to the foundation wall thickness of Fuller Laboratories as both buildings have four stories, brick veneers, and are located on adjacent sites. The buildings also have similar uses as Fuller Laboratories houses computer labs, classrooms, and lecture halls. The Fuller Laboratories foundation wall is also 12" thick, indicating that this thickness was appropriately sized.

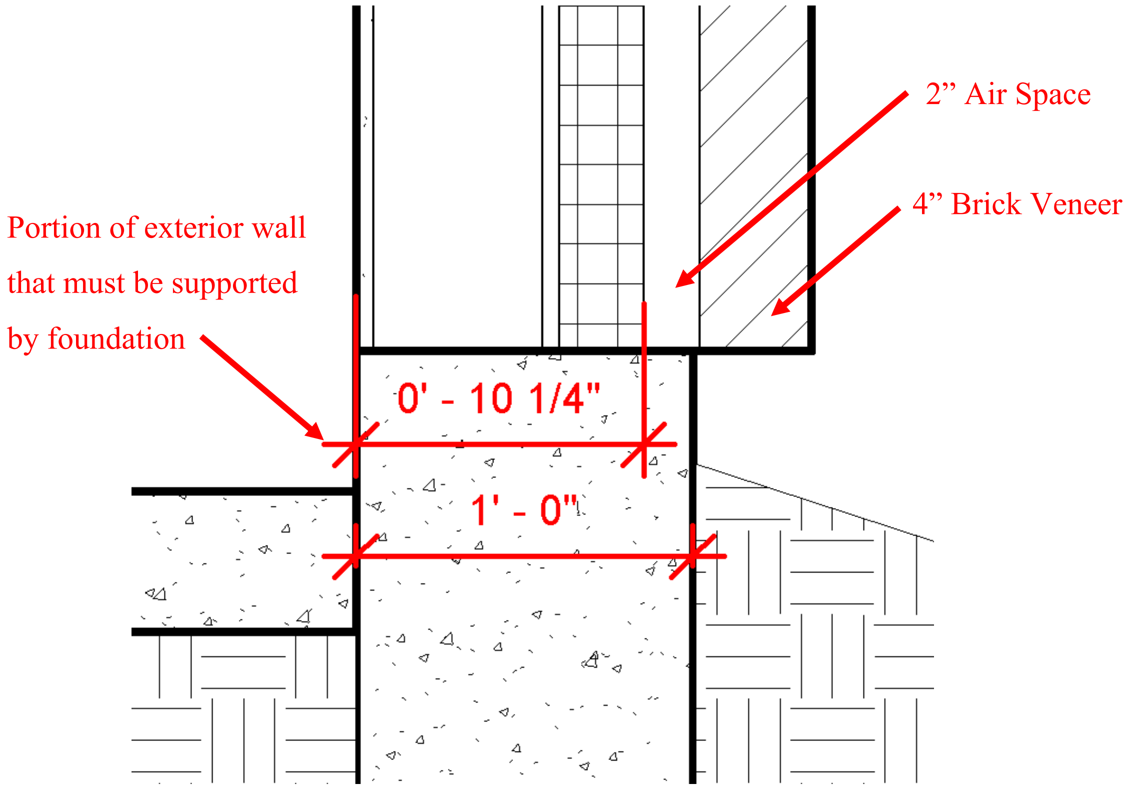
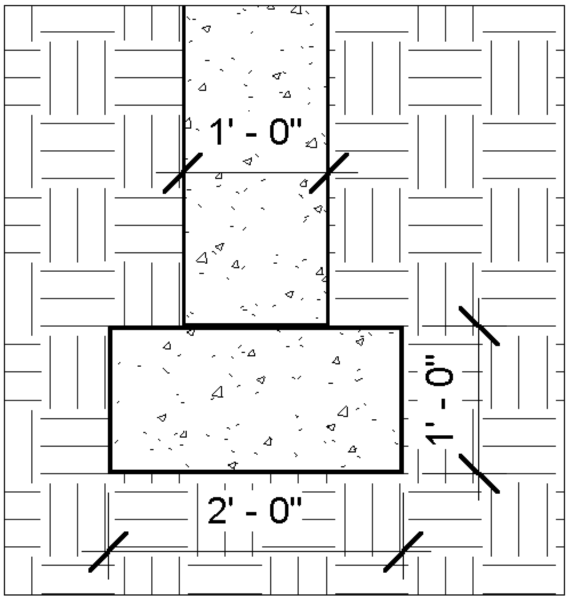


Figure 31: Portion of Wall Supported by Foundation

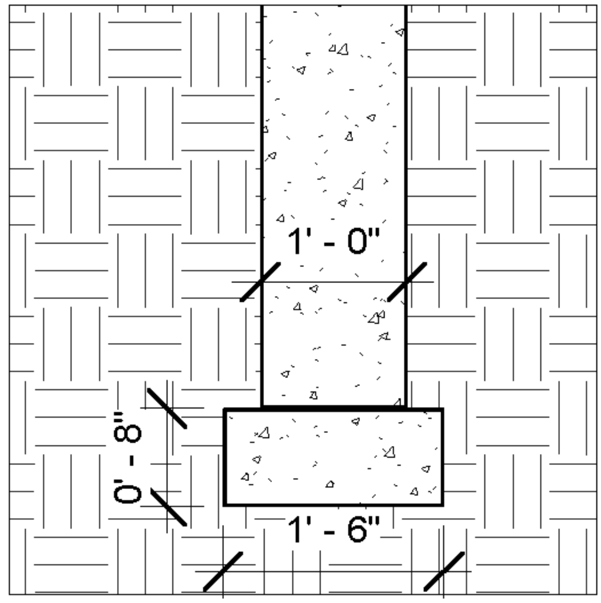
The depth of the foundation is dependent on the depth of the frost penetration line at a given location. The frost penetration line is the depth beneath the ground surface that a freezing temperature can occur. In Worcester, Massachusetts, this depth is 60 inches as determined in Figure 1809.2 of the *2015 International Building Code Illustrated Handbook*. This minimum depth is acceptable for the WPI building because the incline of the hill will ensure there is more than 5 feet of depth at every point uphill from the base of the building. Therefore, a five-foot depth was selected for the foundation wall.

The typical thickness of footings for a three-story building is listed as 8” in Table 1809.7 of the 2015 IBC. This indicates that the footings for the three-story section of this building can be 8” thick while the footings for the four-story areas must exceed this 8”. Based on the drawings provided for the Fuller Laboratories, the footings for the four-story building are 12” thick. Therefore, this building has 8” thick footings for the upper foundation and 12” thick footings for the lower foundation. The width of the footings can also be determined from Table 1809.7 that prescribes an 18” wide footing for three-story buildings. This value is used for the upper foundation and the higher value of 24” is used for the lower foundation based on the adjacent

Fuller Laboratories building. These values provide the following footing design for the upper and lower foundation walls in Figure 32.



Upper Wall



Lower Wall

Figure 32: Typical Upper Wall (Left) and Lower Wall (Right) Footing Design

These dimensions can be confirmed by dividing the column load by the footing area and comparing this value to the bearing capacity of the soil. A sample of these calculations can be found below in Table 34.

Table 34: Footing Load Calculation

		Comments
Column Identification:	A3	
Column Load	452347 lbs	Calculated as described in Section 3.8
Footing Area	51.5 ft^2	2 ft. wide footing x 25.75 ft. tributary length
Distributed Footing Load	8783.44 lbs/ft^2	
Bearing Capacity of Glacial Till	20000 lbs/ft^2	10 tons/ft^2 as stated in Table 1806.2a of the Massachusetts Amendments to the International Building Code 2009

As seen in the calculation, the footing load is less than the bearing capacity of the glacial till, indicating that the footings sizes are acceptable.

3.11 Total Weight of Steel

After sizing all the girders, beams, joists, and columns, the total weight of steel in this building was calculated. This number, when divided by the total square footage of the building, provides verification that the member sizes are accurate. In most four-story, commercial buildings, there are roughly 8 to 10 pounds of steel per square foot. In this building, there are just over 320,000 pounds of steel for 41,209 square feet to equal about 8 pounds per square foot as seen in the calculation shown in Figure 33. As this 8 pounds per square foot is just below the expected range, this system is likely appropriately sized.

Total Column Weight		48609.83 lb
Total Framing Weight	+	271797 lb
TOTAL:		**320406.83 lb**
Square Footage	÷	41209 SF
Pounds per Square Foot	**=**	**7.78 lb/SF**

Figure 33: Pounds per Square Foot Calculation

3.12 Conclusion

The structural system of this building was selected based on 1) flexibility, 2) constructability, 3) cost, 4) thermal performance, and 5) fire resistance. The system was then designed to satisfy all the gravity loads and lateral loads from the occupancy, materials, and environment. This design consists of a rigid steel frame with a concrete foundation. Both the horizontal and vertical members needed for this frame were sized and analyzed based on the applicable loads of the system. This structural design satisfies the three major project objectives as it provides flexible learning spaces for the expansion of the AREN program and WPI as a whole.

4 Mechanical Design

A mechanical system is important for a building to keep the interior conditions comfortable for the occupants. To fulfill the environmental needs, this building was designed with two mechanical systems. However, before the system was chosen, peak heating and cooling loads for the rooms were determined followed by a zoning analysis that was dependent on the rooms' loads, functions, and orientation. These calculations allowed the system to be sized accurately to provide required comfort. In conclusion, an all-air system supplies the top two floors while an air-water system conditions the bottom two floors.

4.1 Load Calculations

The peak loads are dependent on a number of variables including wall materials and orientation, size and number of windows per room, lighting, and occupant load. When analyzing the loads from the bottom floor to the top, the heat gain was noticeably larger on the top floors. This relationship was expected due to the additional traffic on the upper floors and more above-grade exterior wall area. The peak sensible cooling load due to the skin of the building (walls, roof, and glass) was calculated to be 379 MBH while the peak sensible internal load (lights, people, equipment) had a value of 532 MBH. These two values resulted in a total building heat gain load of 911 MBH. A matrix of these loads can be found in Table 35, which summarizes the loads per floor and the building totals, and Appendix E, which summarizes the peak heating and cooling loads in each room.

Table 35: Matrix of Summary Loads (BTUH)

Level	1	2	3	4	Building Totals
Walls	4,042	6,294	6,314	6,637	23,288
Roof	0	0	0	20,531	20,531
Glass	43,893	60,524	96,677	133,968	335,062
Skin	**47,935**	**66,818**	**102,991**	**161,136**	**378,880**
Lights	8,337	19,075	18,820	20,594	66,825
People	11,750	38,750	59,250	122,750	232,500
Equipment	22,591	89,233	100,619	20,341	232,784
Internal	**42,678**	**147,057**	**178,689**	**163,685**	**532,109**
Subtotal Sensible	**90,613**	**213,876**	**281,680**	**324,821**	**910,989**
Ventilation	12,436	34,924	53,943	93,695	194,997
People Latent	9,400	31,000	47,400	98,200	186,000
Ventilation Latent	6,542	18,374	28,380	49,293	102,589
Subtotal Latent	**15,942**	**49,374**	**75,780**	**147,493**	**288,589**

To account for these large loads, four rooftop units were required in this design. The first two units supply the fourth floor with a capacity of 14 tons each, and the third unit supplies the third floor with a 25-ton capacity. These units provide heating, cooling, and ventilation. The last unit, a 15-ton unit, supplies the bottom two floors. This unit is a 100% outside air unit for ventilation. Through ventilation, it will provide some cooling, however, not nearly enough to accommodate for the full load. Therefore, fan coil units are used to supply the heating and cooling on the bottom two floors. These two floors both have much smaller loads at 1 ton because they were sized by the ventilation load required. A riser diagram illustrating this can be seen in Figure 34.

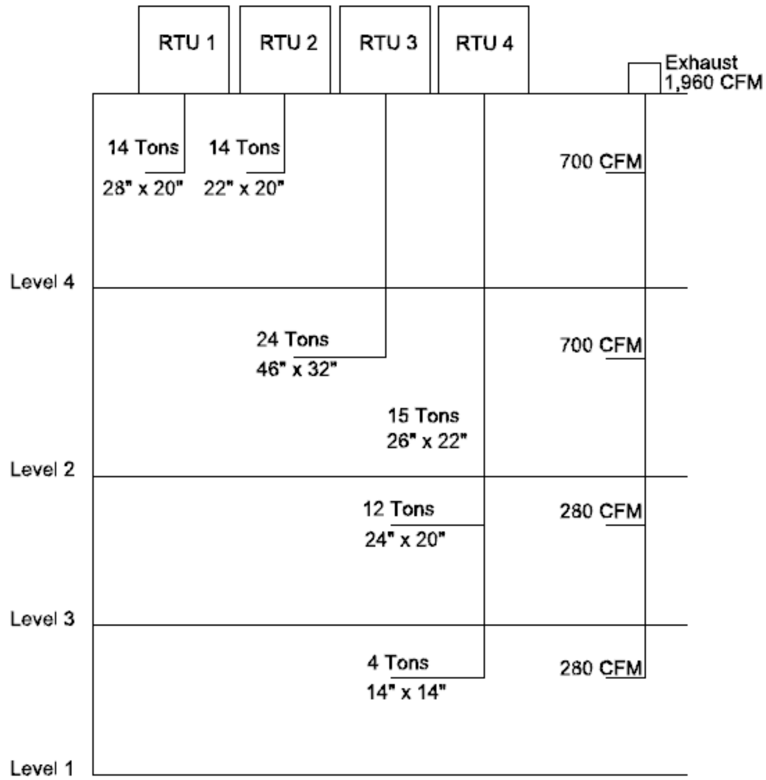


Figure 34: Riser Diagram of Roof Top Units (RTU)

4.1.1 U-Value

U-value is a measurement of the amount of heat transmission through a building's elements. The building's glass, wall, and roof all have different U-values because they are composed of different materials. U-values are calculated taking the inverse of the sum of each element's resistance value (R-value) within the system. The higher the R-value means the greater insulating power while the opposite is true for the U-value. Table 36 shows the building's exterior wall components, R-values, and the total U-value of the wall that was calculated to be 0.054 BTU/hr-ft^2-F. While each component of a wall assembly has a standard R-value, the R-value of metal studs in a wall are calculated differently. To determine the stud wall R-value, the metal stud and air space between studs must be considered separately as stated in ASHRAE 90.2-2010 Table A9.2B, which can be found in Appendix F. The stud wall used in this design is 16 inches on center and is not insulated, yielding an R-value of 0.79 hr-ft^2-F/BTU.

Table 36: Wall U-Value

Wall Component	**Thickness (in.)**	**R-Value**
Brick	4	0.44
Air Space	2	1.02
Rigid Insulation	3	15
Water Resistant Membrane	0	0
Exterior Sheathing	0.625	0.56
Uninsulated Steel Stud Wall (16 o.c.)	6	0.79
Finish	0.625	0.56
	Total	**18.37**
	U-Value	**0.054**

Many of the rooms in the building have exterior walls that are underground. Since these walls have different components and different below-grade depths, the U-values differ. Table 7.10A from the *Cooling and Heating Load Calculation Manual* was used to determine the U-values that are dependent on the underground wall depths as seen in Appendix H (Rudoy). The "insulation over full surface" and "R-8" columns of the table were used in these calculations.

The roof and window U-values needed to be determined separately due to the difference in materials. The glass U-value was determined from a manufacturer's specifications for a Wausau Window SuperWall with a 3/8" airspace. This window has a U-value of 0.42 BTU/hr-ft^2-F. The roof is composed of steel decking with three-inch insulation, yielding a U-value of 0.037 BTU/hr-ft^2-F.

4.1.2 Heat Loss

The peak heat loss value is used to determine the size of the heating system. This value can be calculated using the same equation for the walls, glass, and roof. Equation 23, seen below, is dependent on the difference in interior and exterior temperature, the surface area, and the U-value, which varies for each component. The change in temperature is the difference between the design temperature inside and the temperature outside.

$$BTUH = U * A * \Delta T$$ *Equation 23*

4.1.3 Heat Gain

In order to size the system, the peak heating and cooling loads were calculated using the peak month and time as well as full occupancy and equipment loads. These loads determine the size and type of system that is best for a building.

To help better organize the data, an Excel spreadsheet was used to simplify the repetitive calculations performed on each room. A large factor in determining the heat gain is finding the peak month and hour for each wall, dependent on the wall's orientation. Transmission heat gain can then be calculated for the wall, glass and roof using the Cooling Load Temperature Difference (CLTD), U-value, and area of each (Equation 24). CLTD is the rate at which heat enters a space through a building's materials. The CLTD chart is dependent on time of day, time of year, and construction type. The Cooling Load Temperature Difference and Cooling Load Factor (CLF) are values used to convert space sensible heat gain to space sensible cooling load (Cooling Load Calculation, n.d.). CLF is not used in transmission heat gain calculations but is used when determining solar heat gain through windows. In addition to CLF, solar heat gain is also dependent on factors such as shading coefficient (SC) and a solar heat gain factor (SHGF) (Equation 25). SC is a measurement of heat gain passing through a window depending on the type of glass the window contains and is a ratio of the given glass type to a standard unshaded reference window. SHGF is dependent on the latitude, month, and wall orientation. This is due to the sun changing positions throughout the time of year and the angle at which the sun's rays reach the building's surfaces. Once those values were calculated per room for this building, they were summed together to get the total solar and transmission heat gain per room, per floor, and for the entire building.

$$BTUH = U * A * CLTD$$ *Equation 24*

$$BTUH = A * SC * SHGF * CLF$$ *Equation 25*

4.1.4 Peak Loads

Peak loads are broken down between the roof, glass, wall, and internal heat gains. The roof and wall gains were found to be the smallest at 2% and 3% of the total load, respectively.

The glass heat gain was the next largest at 37% of the total load. Table 37 shows the peak load breakdown below. This large heat gain load from the glass is a result of the building having a large glass area with a high U-value in comparison to the wall U-value as explained above. The building's total glass area is 7,063 ft^2 and has a total wall area of 10,223 ft^2.

Table 37: Heat Gain Load Breakdown

	Wall	Roof	Glass	Internal
Total BTUH	23,288	20,531	335,062	532,109
% Building BTUH	3%	2%	37%	58%

The internal load is 58% of the overall building cooling load (Table 37). This load consists of three categories; lighting, people, and equipment. The lighting is 12% of the internal load, and the people and equipment each make up 44% of the load as seen in Table 38. The people and equipment loads are large due to the building offering rooms with high occupancies such as lecture halls, labs, and studio space. These complete calculations can be found in Appendix F.

Table 38: Internal Load Breakdown

	Lighting	Equipment	People
Total BTUH	66,825	232,784	232,500
% of Internal BTUH	12%	44%	44%

The lighting was designed with LED fixtures to provide a high energy efficiency. A total of 508 fixtures are in the building creating a load of 66,825 BTUH. This load only resulted in 12% of the total internal load at 0.47 W/ft^2. According to the 2015 IECC standard for university buildings, the interior lighting load should remain below 0.87 W/ft^2. Since the lighting is creating a smaller heat gain, the cooling load can stay lower and, in result, reduce energy costs.

The people and equipment loads are both calculated by room. The sensible people load is determined by multiplying the number of occupants by the industry standard of 250 BTUH per person. The equipment load is determined by multiplying the wattage of the item by 3.41 BTUH/Watt. Table 39 shows the list of equipment within the building in addition to the wattage and BTUH for each item. The total people and equipment loads were marginally different at 232,500 BTUH and 232,784 BTUH, respectively. These loads are expected to be higher due to the large occupancy loads and designed workspaces within. This can been seen in rooms such as computer labs and lecture halls which have noticeably higher heat gain.

Table 39: Building Equipment

Equipment	Watts	BTUH
Projector	400	1364
Desktop	300	1023
TV	175	597
Printer	625	2131
Projector	18	61
Refrigerator	500	1705
Microwave	1000	3401
Coffee Pot	800	2726
Copier	1400	4774

4.2 Zoning and CFM Calculation

Once the total sensible loads are determined, the amount of air required to condition each space can be calculated. Airflow is measured by cubic feet per minute (CFM). The CFM required of each space, based off the respective peak load, can be calculated using Equation 26.

$$CFM = \frac{BTUH}{1.1 * \Delta T} \qquad \textit{Equation 26}$$

The change in temperature represents the difference between design space temperature and supply air temperature. A design temperature of 75°F is used for cooling. 75°F is standard practice and is within the comfort zone found in ASHRAE Standard 55. The supply air temperature typically ranges from 55°F to 58°F and is chosen based on the system selection and the respective relationship between sensible and latent capacity. In packaged equipment, supply air temperature is a function of what the unit can deliver. In applied equipment, such as the equipment in this building, the supply air temperature is selected to avoid cost of excessive latent cooling. Latent capacity increases as the supply air temperature decreases. Conversely, the CFM required decreases as supply air temperature decreases. As seen in Equation 26, CFM and ΔT are inversely proportional, therefore, as ΔT increases, CFM will decrease. A reduction in CFM requires smaller duct sizes which is ideal as shaft space needs to be considered. The design temperature used was 56°F to not only reduce duct sizes, but also limit the latent capacity.

Table 40: CFM Overview

	1st Floor	**2nd Floor**	**3rd Floor**	**4th Floor**	**Total**
Area (ft^2)	6,724	11,495	11,495	11,495	41,209
Occupants	45	140	237	491	913
Cooling CFM	4,304	10,277	13,486	15,394	43,461
Ventilation CFM	595	1,671	2,581	4,483	9,330
Exhaust CFM	280	280	700	700	1,960

Table 40 above displays the total cooling CFM required per floor, as well as the total for the whole building. A more detailed table with CFM per room on each floor can be found in Appendix E. The CFM increases from the first floor to the fourth. This corresponds with the trend of increasing sensible load described previously, as it should, given that the two values are directly related. As shown in Table 40, the building requires about 43,500 CFM. The ASHRAE standards suggest that for buildings with walls consisting of 40% windows the ratio of total CFM to total building square footage should be around 1. This building has 43,461 CFM to 41,209 square feet, for a ratio of 1.05, slightly over the standard but still an acceptable ratio.

In accordance with the *International Mechanical Code* (IMC), buildings are required to provide ventilation to all occupied spaces. The ventilation provides outdoor air, also referred to as fresh air, to the occupants. Table 40 displays the minimum CFM of outdoor air required for each floor. This data follows the same trend of increasing values from the first floor to the fourth as the occupant load increases with each floor. The minimum required CFM of outdoor air per room is determined by the number of occupants and floor area. The specific CFM/sf and CFM/occupant values for each room type can be found in Table 403.3.1.1 of the 2015 IMC. For this building, the ventilation CFM is significantly less than that required of the cooling load at only 9,330 CFM for the whole building. A detailed analysis of ventilation air required per room can be found in Appendix J.

Appendix J also displays the required latent loads. The latent capacity is influenced by the amount of people in the room. It can be calculated by multiplying the occupant load by the latent capacity per person, 200 BTUH/person. Like ventilation, the latent capacity needs to be provided by outdoor air. The third and fourth floors have an all-air system sized according to the sensible load. The latent load can be handled within the requirements of the sensible load. However, the air system of the first and second floor is sized based on the minimum CFM required, which is the larger of the ventilation and latent CFM requirements. The latent CFM is calculated using Equation 27.

$$CFM = \frac{BTUH}{0.68 * \Delta W} \quad \textit{Equation 27}$$

BTUH is the latent capacity based on the occupant load. ΔW denotes the change in grams per pound, which represents the humidity ratio. For this equation, 7.91 is used for ΔW. It is the difference between the indoor design conditions, 75F dry bulb and 50% relative humidity, and the conditioned supply air, 53F dry bulb and 95% relative humidity. The respective humidity ratios can be found using the psychrometric chart in Appendix K.

The IMC also requires buildings to exhaust air in certain spaces as part of the ventilation code. These spaces typically include restrooms and kitchens. Exhaust is necessary to remove odor and contaminated air from spaces. Exhaust air is never to be recirculated throughout the building. This building does not contain a kitchen or any other space requiring exhaust other than the restrooms. The 2015 IMC requires 50 CFM to 70 CFM of exhaust per toilet or urinal. 70 CFM was used to maximize the exhaust air that will be used for energy recovery.

Table 40 displays the required exhaust CFM per floor. Each floor has two restrooms. The first two floors contain two fixtures per restroom, totaling four fixtures at 70 CFM each for 280 CFM per floor. The top two floors have five fixtures per restroom to handle the higher occupancy loads. Ten fixtures at 70 CFM each results in 700 CFM per floor. The exhaust totals to 1,960 CFM for the entire building.

Once the CFMs were determined for each room, zones needed to be established for the system design. Zones are spaces consisting of one or multiple rooms that are conditioned independently from other zones. Each zone is controlled by a single thermostat. The zones for this building are shown in Appendix I. Zones are established based on use, orientation, and required load. The offices on the second floor, shown in Figure 35, provide a good example. The interior offices are grouped into one zone. They have the same use and similar loads, and the orientation is irrelevant because they are internal spaces. The north offices form another zone. They have the same use, similar loads, and same orientation. However, Offices 1, 2, and 3 are all part of different zones. They have the same use, but different loads and orientations.

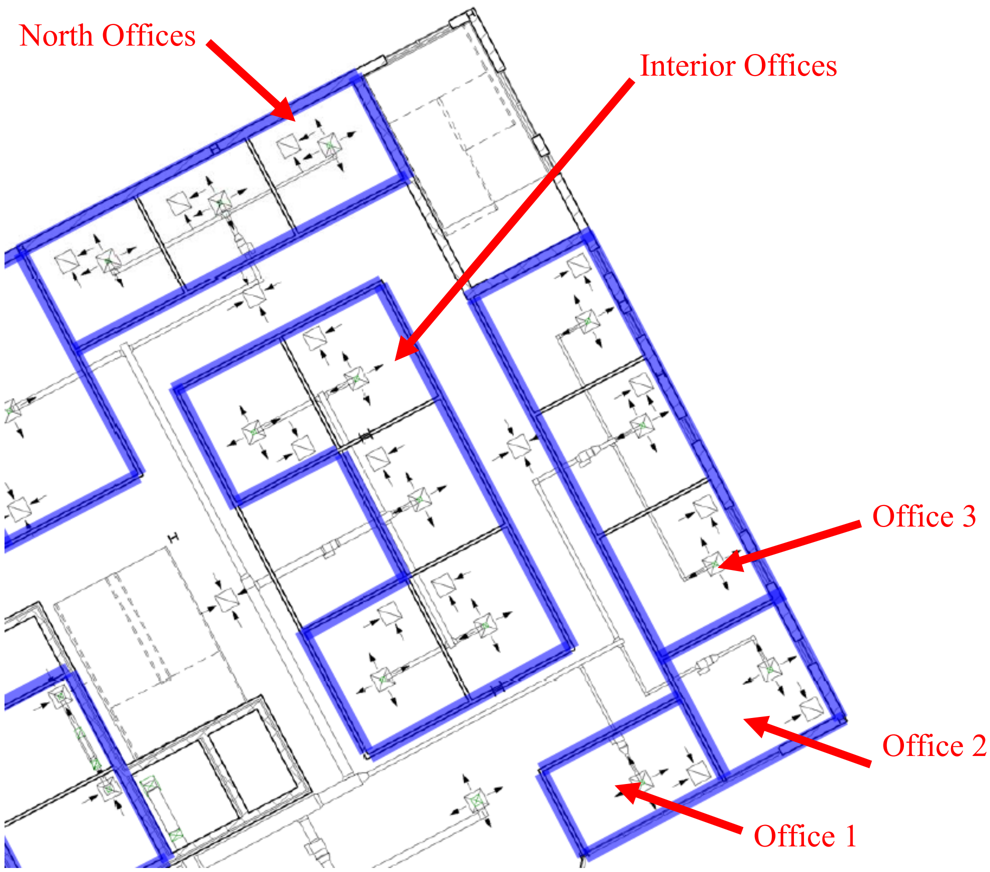


Figure 35: Office Zoning

Perimeter rooms facing different directions will have peak loads at different times, making it inefficient to place those rooms in the same zone. The storage rooms are not part of any zones because they do not require any conditioning. The hallways are also not zoned because they are conditioned by adjacent spaces. Open spaces throughout each floor will supply extra CFM to meet the additional loads from the hallways. Hallway loads are typically small and rarely fluctuate. Once all the zones are established, an adequate system can be chosen to supply all their respective CFM requirements.

4.3 System Selection

A combination of an all-air system and an air-water system was selected as the main mechanical system in this building. An all-air system uses ductwork to supply air to cool and heat the building. The traveling air through that ductwork is supplied by an air-handling unit, usually located on the roof. The air-handling unit has a designated outdoor air intake to meet the building's ventilation requirements. Since the central plant is located in an unoccupied area, operation and maintenance are consolidated and the issues associated with noise and odor are reduced. The system does not require any major piping, electrical equipment, or filters in the indoor conditioned space. The system provides good design flexibility for optimum air distribution and local requirements. It allows for simultaneous heating and cooling in various zones and can maintain precise temperature and humidity conditions. It is adaptable to automatic seasonal changeover and can include energy conservation features such as an economizer. It is also adaptable for required fire and smoke removal systems. All of these features make an all-air system ideal for the building design.

An air-water system uses both an air system and a water system to condition the space. The air system brings in the required ventilation through ductwork, which is routed from an air-handling unit using 100% outside air. The water system provides the heating and cooling, distributed by terminal units, such as fan coil units. In this case, hot water is pumped from a boiler, and cold water is pumped from a chiller to the units in each room. A fan then blows over the hot or cold coils to change the temperature in the room. The fan blows 100% recirculated air, which is why ventilation is required. However, the ventilation required is much less than the CFM needed to cool the space, resulting in smaller ductwork that occupies less space in the plenum. The ventilation CFM does provide some cooling, reducing the required load of the fan coil units. Still, a much smaller air-handling unit is needed. This system is comparable to the all-air system in terms of versatility and capability. It can provide zone temperature control and zone heating and cooling independently. Air-water systems typically have lower operating costs because the power required to pump water is less than the power required to operate a fan to supply air. Although, this system typically has more complex controls and it is not ideal for seasonal changeover. Overall, an air-water system is ideal for perimeter zones, because the fan coil units can handle the higher loads near glass well, as compared to an all-air system where there can be cold spots.

The building was essentially split into two, with the top two floors conditioned by an all-air system and the bottom two floors conditioned by an air-water system. Each system was designed with the application for which it was best suited. The top two floors are ideal for the all-air system. There is plenty of ceiling space to contain the larger ducts, with 5' 3" of space on the fourth floor and 4' 1" on the third. Also, less shaft space is needed, given the location of the air-handling units on the roof. The system uses a return air plenum so there is no need for return air ducts other than the vertical ducts in the shaft. Each floor is conditioned by its own air-handling unit, providing both heating and cooling. Each unit requires a cooling coil and needs to be piped to the chiller. Although the units provide heating, they contain no preheat coil. Mixing the return air with the outdoor air provides the majority of the heating. The rest is provided by the terminal boxes. The specific system used is a variable air volume system (VAV). VAV systems alternate the quantity of air supplied to a space to condition it based off the respective load. Each zone has a fan-powered box to control the amount of air supplied. The fan-powered boxes are piped with hot water for reheat. Each box has a minimum CFM, which is required for ventilation. Sometimes the load will require less CFM than the minimum CFM of the fan powered box. Hot water is piped to a coil in the fan-powered box to increase the temperature of the supply air to prevent overcooling. VAV systems are ideal for supplying multiple zones because they are very efficient, easy to control, and flexible in design.

The bottom two floors are better suited for a 4-pipe fan coil system, a specific type of air-water system. The ceiling space is limited, so there is not enough room for large ducts. Each floor has about 3' 7" of ceiling space, and contains structural girders as deep as 30". However, there are only four 30" girders that can be avoided with careful coordination. Thus, the required ductwork to handle the slight ventilation requirement is limited to about 20" of vertical space. The rectangular ducts are less than 14" deep in order to have a little flexibility and save space for lights, sprinklers, etc. Since the ventilation air quantity is only about 7,605 CFM, only one rooftop unit was required to supply both floors. The ventilation air is distributed using fan-powered boxes. Unlike the VAV system used in the top two floors, these boxes supply air at constant volume. The ventilation air supplied provides some cooling, so the loads carried by the fan coil units in each room can be reduced. The fan coil unit chosen for use in the rooms is the Carrier 42CG. For aesthetics, this unit is ceiling mounted, instead of a cabinet or stack unit, which also reduces noise. The unit can contain two coils, which is required for the 4-pipe system. One coil is for heating, and one coil is for cooling. Two pipes provide hot water supply and return to and from the boiler. The other two pipes provide cold water supply and return to and from the chiller. The boiler and chiller are located nearby in the mechanical room on the first floor so piping can be limited. The 42CG also ranges in sizes, handling loads from 4.4 MBH to 25 MBH, a perfect range given the required loads in the first and second floor rooms.

4.4 Layout and Sizing

Duct sizing is dependent on CFM, friction rate, and velocity. A ductulator is used to simplify the process of sizing ducts. When sizing the ductwork for any given CFM, the pressure drop, or friction rate, of low pressure ducts is maintained around 0.08 in/100 ft. Duct mains are sized as medium pressure ducts, not exceeding 0.22 in/100ft. In addition to providing zoning for adequate temperature control, the VAV boxes provide the pressure drop between the high pressure and low-pressure ducts. Sizable difference in static pressure drop throughout the system can cause problems, affecting airflow and hindering the performance of the system. The air speed is also considered. If the airflow, in feet per minute, FPM, is too fast, the system can be loud. Larger ducts can handle more air, reducing the necessary speed, which reduces sound.

When designing the system, appropriately sized diffusers are placed in each room based on the room's load. Most surface mounted ceiling diffusers can typically handle up to 500 CFM without being too loud. Multiple diffusers can be placed in a single room at different CFM values to meet the required load. Ductwork is then routed from the diffusers to the zones' fan-powered boxes and from there to the rooftop units through the ceilings and shafts. See Sheets M101-M104 in Appendix Q for the mechanical layout. When sizing this ductwork, it is very important to coordinate with the architectural designer for ceiling space and with the structural engineer for beam locations and depths. The ducts must be sized to fit within the given space. They also should be routed to avoid firewalls and structural walls. Once the ducts are laid out and sized, the return air system needs to be placed. This system uses a return air plenum, eliminating the need for additional ductwork in the ceiling space. Instead, each zone has return diffusers matching the CFM of the supply diffuser, drawing that air into the plenum. The return air in the plenum travels through the open space of the plenum, or transfer grilles if necessary, and is drawn through a main shaft by a fan.

The layout has several special circumstances. The lecture halls do not just have conventional supply diffusers; they also have linear diffusers for aesthetic purposes. In addition, supply air is not delivered to the corridors. However, the supply air quantity delivered to adjacent spaces open to the corridors includes the capacity for the corridor loads. Return grilles sized for the hallway loads are placed in the hallways to draw the extra air from the adjacent spaces and condition the hallways. The restrooms do not have supply diffusers either as they do not require supply air. The restrooms are interior spaces with no permanent occupancy, so the load is negligible. However, the restrooms still need make up air to compensate for the toilet exhaust. To avoid ducting through the core wall surrounding the restrooms, transfer grills are used.

Another special circumstance is the load in the stairways located on the perimeter of the building. These stairs are heated but do not require cooling because it is not an occupied space. Also, providing cooling, whether ducted or not, would require additional penetrations through the wall, affecting the fire rating of the staircase. However, this issue can be protected by using fire dampers. Regardless, Section 1024.6 of the 2015 IBC prohibits a foreign system in an egress stair. However, the cooling load still needs to be accounted for. The load is proportionally distributed to the adjacent zones, which are oversized to handle the extra load. For example, on the third floor, the open area on the southeast side of the building only requires 1,060 CFM. However, 1,725 CFM is supplied into the zone to account for the adjacent hallways and the extra cooling load from the stairs. The same concept applies to oversizing the fan coil units used on the first and second floors.

Sizing the ductwork for the ventilation on the first and second floors requires the same design process as previously discussed. Once the CFM values are appropriately assigned to each zone, the available cooling load from the ventilation air can be calculated and subtracted from the total cooling load per room. The remaining load is then used for sizing the fan coil units for each room. The sizes for the Carrier 42 CG fan coil units are as follows in Table 41. For more details on the selected fan coil units, see the Carrier specification sheets in Appendix L.

Table 41: Carrier 42 CG Unit Sizes

Unit	2	3	4	6	8	10	12
Total MBH	6.0	9.0	12.1	17.3	22.6	27.5	32.8
Sensible MBH	4.4	6.3	8.8	13.0	16.2	21.0	25.0
CFM	200	300	400	600	800	1000	1200

The fan coil units placed in each room should be sized accordingly. Multiple units can be used if necessary. Table 42 below shows the fan coils units attributed to each room. The first column shows the minimum required CFM, based on the larger of the ventilation and latent requirements. The next column shows the sensible load acquired from the minimum required CFM, using 22 for temperature change, given 75F design temperature and 53F supply. This is subtracted from the total required sensible load to determine the remaining sensible after the ventilation air is supplied. The remaining sensible is used to determine what size(s) fan coil unit to put in each room. For example, Office 1 on second the floor has about a 10,000 BTUH remaining sensible load. Referencing Table 41, unit 6, which can handle up to 13 MBH sensible, is selected for this room. The computer lab has a sensible load of 25,680 BTUH, requiring more than one unit. Unit 6 and unit 8 are selected to handle a combined load of 29.2 MBH. Some rooms do not even need a fan coil unit.

Table 42: Fan Coil Unit Selection

First Floor							
Room	**Min CFM Required**	**Sensible BTUH**	**Required Sensible BTUH**	**CFM required (no FCUs)**	**Remaining Sensible BTUH**	**Actual CFM**	**Fan Coil Unit**
TA Offices	735	17787	36732	1518	18945	735	6,3
Student Lounge	920	22264	37745	1560	22663	920	8,4
Mechanical Room	35	847	2144	89	5409	35	3
Total	**1690**	**40898**	**76621**	**3167**	**47017**	**1690**	

Second Floor							
Room	Min CFM Required	Sensible BTUH	Required Sensible BTUH	CFM required (no FCUs)	Remaining Sensible BTUH	Actual CFM	Fan Coil Unit
Office 1	40	968	10951	453	9983	40	6
Office 2	40	968	5862	242	4894	40	3
Office 3	40	968	3654	151	2686	40	2
Office 4	40	968	2678	111	1710	40	2
Office 5	40	968	3653	151	5504	40	3
Office 6	40	968	2074	86	3845	40	2
Office 7	40	968	1936	80	968	80	-
Office 8	40	968	2079	86	1111	90	-
Office 9	40	968	1620	67	652	70	-
Office 10	40	968	1620	67	652	70	-
Office 11	40	968	1620	67	652	70	-
Office 12	40	968	1620	67	652	70	-
Office 13	40	968	1620	67	652	70	-
Admin Area	40	968	2113	88	1145	90	-
Faculty Lounge	735	17787	15100	624	-2687	735	-
Copy Room	15	363	8107	335	7744	15	4
Computer Lab	1850	44770	70450	2911	25680	1835	8,6
Conference Room 1	550	13310	7803	322	-5507	550	-
Conference Room 2	370	8954	9164	379	210	380	-
Conference Room 3	550	13310	14153	585	8135	550	4
Open Area	550	22264	18019	745	2670	920	2
Total	**5180**	**134310**	**185896**	**7684**	**71351**	**5835**	

If the remaining sensible load is small, around 2000 BTUH or less, then a fan coil unit is not needed. Instead, the total load can be handled by airflow. This applies to all the interior offices and some other spaces with small sensible loads. It would not be efficient to install a unit that can handle 4.4 MBH, the smallest option, to cool a room that only requires 652 BTUH. The actual CFM column shows the CFM distributed to the room. If there is no fan coil unit selected, the actual CFM is high enough to handle the sensible load. If a fan coil unit is selected, the actual CFM represents the airflow required to meet just the minimum CFM requirement. This can be compared to the column showing CFM required assuming there is no fan coil unit, which is based on the total sensible load. It should be noted that Table 42takes into account loads associated with the corridors and egress stairs. Their requirements are applied to the adjacent spaces that will handle the additional loads, and the accompanying values for minimum required CFM and remaining required sensible BTUH have been updated accordingly.

In two cases, the required ventilation CFM causes overcooling. In the faculty lounge and conference room 1, the remaining sensible load is a negative number. This is because the sensible load from the minimum required CFM is larger than the sensible load required of the room. In these cases, reheat is required to counter the possibility of overcooling.

Layout and sizing the pipe system is dependent on the required gallons per minute (GPM) of the piped equipment. The layout consists of a 4-pipe system: two pipes for hot water supply and return and two pipes for chilled water supply and return. Hot water and chilled water pipes are routed to all the fan coil units and only chilled water pipes are routed to the coils in the air-handling units. Additionally, the fan-powered boxes require hot water piping for reheat. Sizing is dependent on required GPM per unit. The fan coil unit has a standard required GPM per unit size for hot water and chilled water. The fan-powered boxes also state the required GPM for the hot water required for reheat. The chilled water coils in the air-handling units require the bulk of the GPM required for the piping system. Pipe sizes are relatively small, with the largest mains no bigger than having a 6” diameter. The runoffs to the units are no larger than 2” diameters. The piping can run throughout the plenum and shaft, taking up virtually no space. Coordination is required for densely populated plenums and shafts, but that is not an issue for this building.

4.5 Equipment Selection

Equipment selection is one of the most important aspects of the mechanical design process. An engineer has to be extremely precise to ensure that the specified units will be able to handle the heating, cooling, and ventilation requirements of the building during the most demanding conditions.

Engineers typically rely on manufacturer performance data and seek help from local representatives to select specific models that fit the project criteria. Most companies have relationships with vendors they often work with which helps facilitate the process. For this project, the design team contacted a vendor at Buckley Associates to help with the equipment selection. Buckley is a local vendor that distributes air-handling units made by Greenheck.

There has to be a lot of communication between the engineer and vendor in order to confidently choose suitable equipment. The engineer has to explain the project in detail to ensure the vendor understands what is needed for the project. The vendor has to understand the type of spaces, ventilation requirements, load requirements, etc. and what type of heating and cooling the units provide. There are several options such as hot water, gas, and electric for heating and split direct expansion (DX), packaged DX, and chilled water for cooling. It is also vital that the vendor knows what purpose the units would serve. For this project, one air-handling unit was selected to serve the fourth floor, meeting all the ventilation, heating, and cooling requirements. This unit would need to be large enough to handle the 15,435 CFM required to supply the floor. It also needs enough outside air to handle the latent and ventilation requirements of the floor. An additional unit was selected for the third floor to serve the same purpose. This unit would need to be able to handle the 13,255 CFM required for the third floor. Both units would need chilled water coils for the cooling systems, as per the building design. The two units should be the same model, just different sizes to handle the different loads on the third and fourth floors. The two floors should have two separate units as opposed to one large unit for several reasons. A single unit that size would have to be custom built. This can be a very expensive option, in terms of both design and operation and maintenance. Also, there would not be enough shaft space to handle the larger, consolidated riser duct if a single unit served both floors. A unit dedicated to serving only the top floor does not require shaft space since it is right above the plenum. This provides convenience when determining location for the riser. It also leaves more shaft space for risers leading to the lower floors.

A third unit would serve the first and second floors. An energy recovery unit that uses 100% outdoor air was ideal for the third unit. Energy recovery units use an energy wheel to provide essentially free heating and cooling as the exhaust air from the building enters the energy wheel and heats or cools the passing outdoor air within the unit. This unit uses 100% outdoor air because its only purpose is to handle the latent and ventilation requirements of the first and second floor. These loads require a combined 7,605 CFM.

Buckley Associates provided selections for three different units, found in Appendix M, based on the building's specific requirements. The largest standard unit offered by Greenheck can handle up to 13,500 CFM. This capacity was enough for the unit required for the third floor, however, not enough to handle the load required for the fourth floor. Buckley offered to provide a custom unit to handle the larger load. After consulting with the vendor, the design team decided it was a better choice to select two 7,770 CFM units instead. In many cases, two small standard units are less expensive than one large, custom designed unit. There is an uncertainty factor to be considered with a custom unit as well. The characteristics of the unit are not specifically defined prior to design and there is a possibility it could not meet the engineer's requests. If noticed, this could cause scheduling issues. If not, it could hinder system performance. Also, there are operation and maintenance benefits associated with standard line units over custom units.

The location of the units needed to be coordinated with the structural engineer to ensure that the roof members can handle the extra weight. The affected members are highlighted in red in Figure 36. After this structural analysis, Girder C23 was increased from a W14x30 to a W18x40. The rest of the horizontal roof supports were adequate for the additional weight of the mechanical equipment.

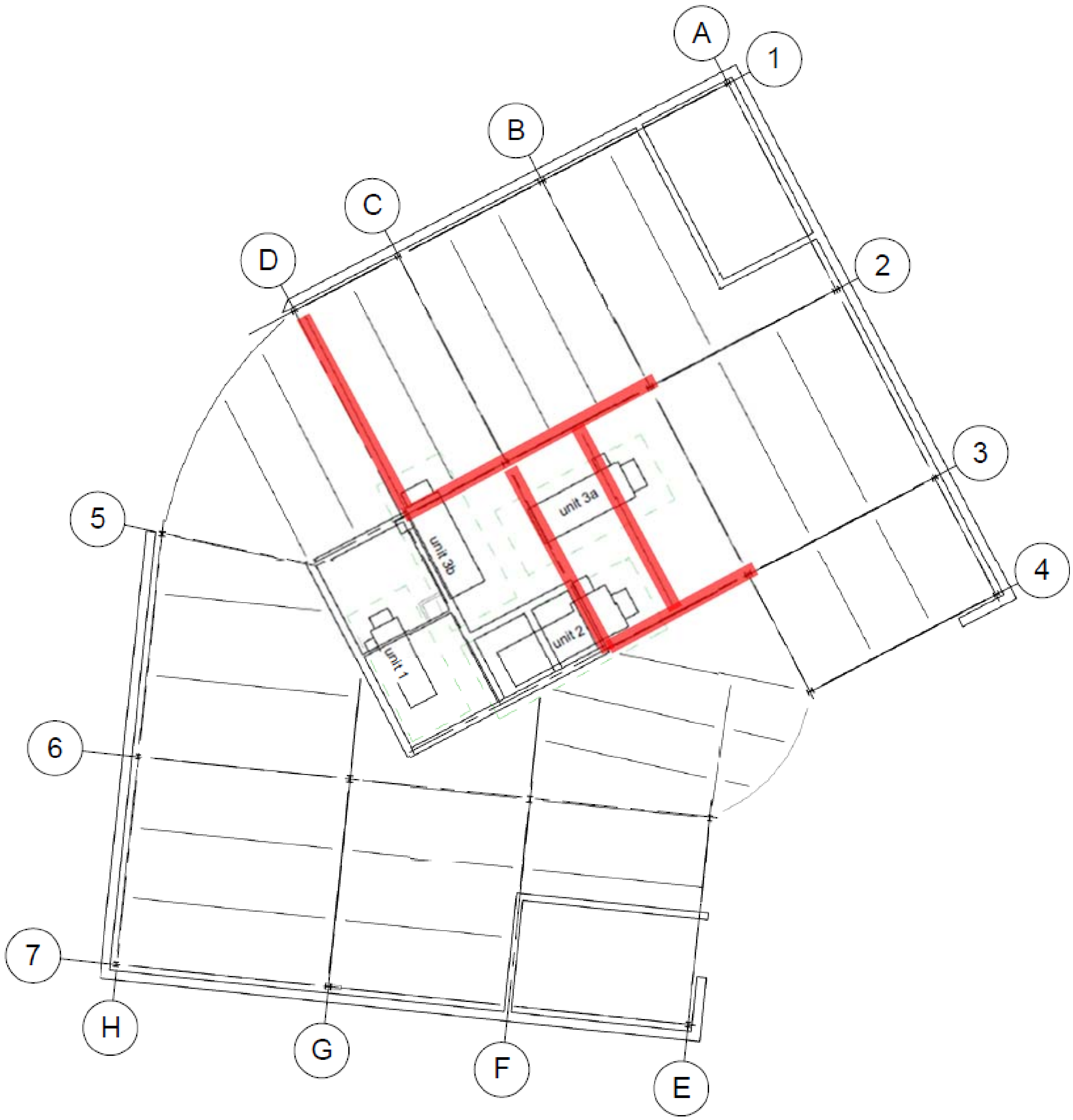


Figure 36: Members Affected by Mechanical Units

4.6 Conclusion

The mechanical system was selected by calculating the peak heating (280,536 BTUH) and cooling loads (906,669 BTUH). To account for the total supplied load of 36,565 CFM for the building, two different systems were chosen: an all-air system and an air-water system. The all-air system supplies the top two floors while the air-water system supplies the bottom two floors. There are two RTUs (14 tons each) that supply that fourth floor due to the large 15,435

CFM load. Because this load is so large, a custom unit would be needed to supply the space. This custom unit would be expensive. Therefore, two smaller units of identical size supply the top floor. The third RTU (25 tons) feeds the third floor, and the fourth RTU (15 tons) supplies the ventilation loads to the bottom two floors. The air-water system supplies the remaining sensible load to the bottom two floors. While some engineers would argue that having two different systems servicing this building may not be the most efficient approach, these systems were selected in order to demonstrate competency in designing both duct and piping systems.

5 Additional Considerations

The complete design of a building requires more than the architectural, structural, and mechanical designs. A complete design requires fire protection, energy analysis, construction management, and much more. The following areas were selected as additional focuses of this project:

1. Fire Protection – An egress analysis and general sprinkler layout were conducted to ensure the safety of the occupants.
2. LEED Evaluation – A LEED evaluation provided information regarding the sustainability of the building.
3. Energy Simulation – An energy model was created to display energy efficiency and performance based on different building performance factors.
4. Cost Estimate – A preliminary cost analysis was conducted based on square footage data and on material data to provide an approximate estimate of the total building cost.
5. Schedule – A schedule of construction activities was created to estimate the duration of the project.

5.1 Fire Protection

Fire protection is important to keep the occupants safe, and the building protected. These systems not only contain sprinklers or fire suppression but alarm and notification devices as well. Sprinkler systems are not designed to extinguish fires but to suppress them long enough for the fire department to arrive and all occupants to evacuate safely. In parallel to fire suppression systems, notification and alarm systems are designed to alert all occupants of the hazard and guide them to safety. A sprinkler was designed within this building.

A sprinkler system layout was designed according to code standards. IBC 2015 states that where a sprinkler system is to be installed within a building it should be installed in accordance to NFPA 13. According to Section 8.5.2.2 of NFPA 13, a sprinkler should have a maximum allowable protection area coverage of 400 ft^2. However, Table 8.6.2.2.1 states that projection areas and maximum spacing for standard pendant and upright spray sprinkler are to be 130 ft^2 and 15 ft respectively. This resulted in a total of 325 sprinklers needed throughout the building design. The sprinkler design drawings can be seen in E101-E104 in Appendix Q.

5.2 Egress Analysis

An egress analysis was performed on the building to map the circulation and flow of the occupants in the case of a fire or emergency. The 3-dimensional building geometry was imported into a software called Pathfinder and within the program, egress doors and occupant loads were placed in their proper locations. With a total building occupant load of 913, two egress stairways, and two main entrances, Pathfinder calculated the egress time would be 222 seconds (3 minutes and 42 seconds) for all occupants to exit safely as seen below in Figure 38. The circulation of the occupants was found to be smooth and have no disruptions within the floorplan. Figure 37 is a capture taken at 8.4 seconds of the Pathfinder simulation.

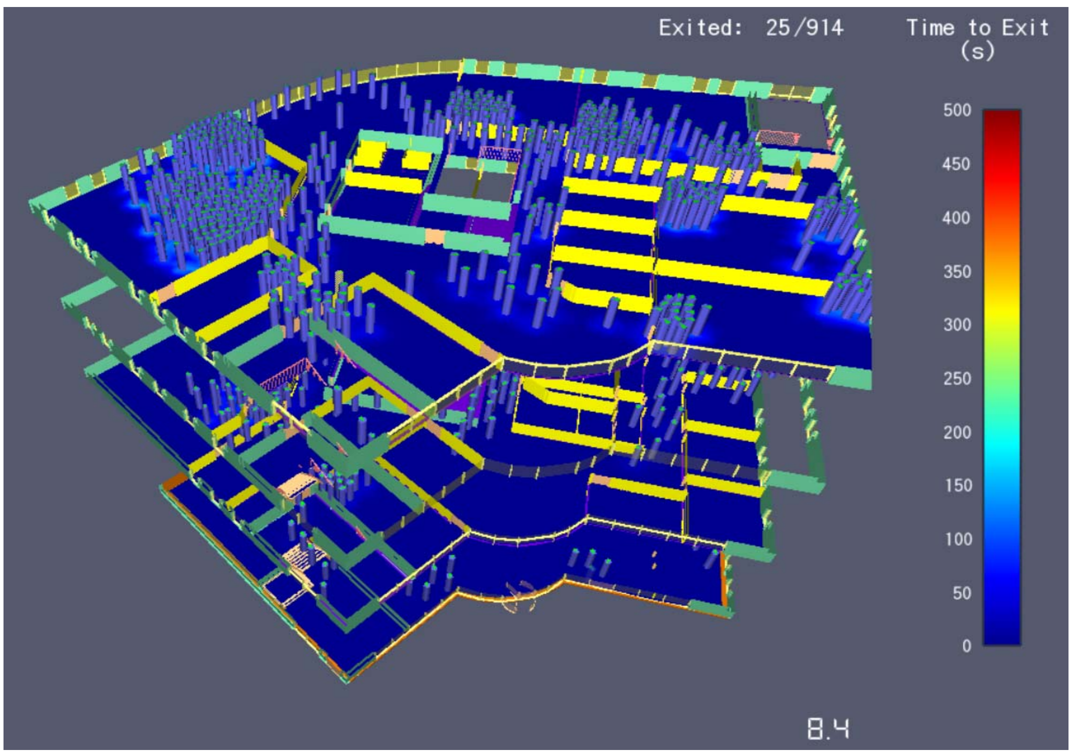


Figure 37: Pathfinder Egress Analysis Simulation Capture

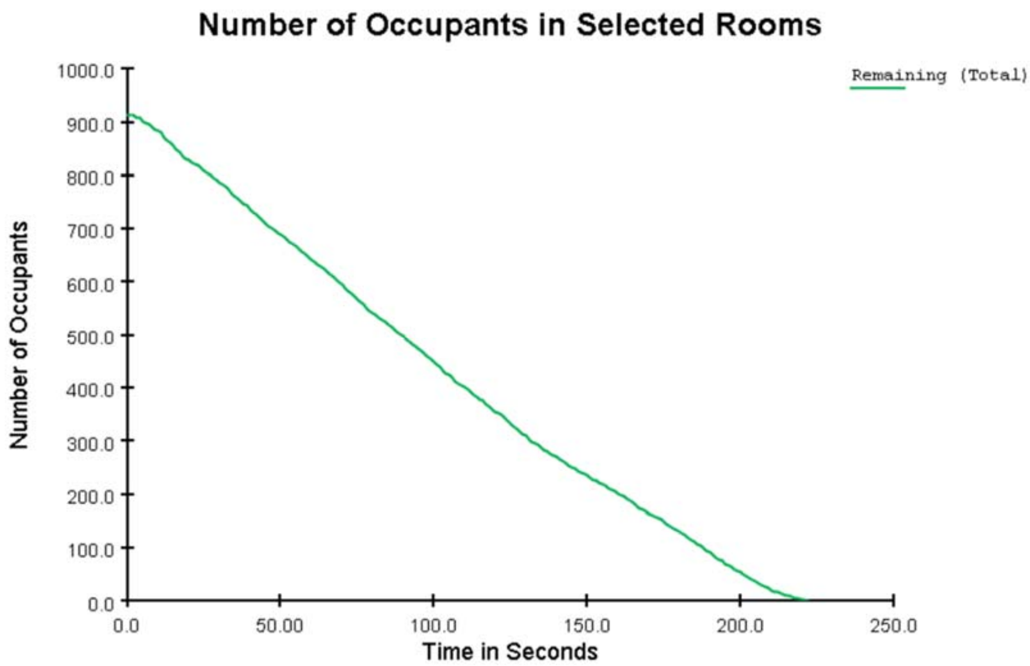


Figure 38: Time of Egress of Occupants

5.3 LEED Evaluation

Leadership in Energy and Environmental Design, or LEED, is the most popular third party verification for green buildings. LEED is a certification program administered by the Green Business Certification Inc. It is conducted through technical reviews and verification of registered projects to determine if they meet the standards set forth by the LEED rating system. Projects can earn points across several areas that address sustainability issues. Based on the points acquired, a project can receive one of four LEED rating levels: certified, silver, gold, and platinum.

Buildings that achieve any LEED certification are resource efficient. These buildings use less water and energy and reduce greenhouse gas emissions. In addition to these sustainability benefits, LEED buildings save money. Having any LEED rating is very good for public relations. Recently, many universities and major companies have been promoting their new LEED certified buildings to heighten their reputations.

LEED is constantly updating their rating system to adapt to relevant issues. The latest version is LEED v4. However, a project is not limited to the latest version; it can apply to any LEED rating system. LEED addresses different types of buildings undergoing varying phases of construction. The most popular is Building Design and Construction, or BD+C. BD+C includes both new construction and major renovation for schools, retail buildings, hospitals, warehouses, and other common types of buildings. The academic building of this project falls within the BD+C designation.

The specific BD+C LEED v3 scorecard was used to rate the proposed academic building. The design team referenced the scorecard for the Integrative Learning Center (ILC) of UMASS Amherst to assist with the scoring. The ILC, completed in 2014, received a LEED gold certification under the v3 rating system. It is similar to the proposed AREN building with regards to building use and design. As seen in Table 43: Overview of LEED Score, the AREN building scored most of its points from the Sustainable Sites, Energy and Atmosphere, and Indoor Environmental Quality categories. Based on the ILC scorecard, the building received points from reduced water usage, increased energy performance, application of low emitting materials, and promoting thermal comfort. Most of the awarded points are speculative, however, the AREN building does have specific features to support some of these points as well. For example, the interior design advocates the use of low emitting materials. Also, the mechanical systems promotes increased energy performance and thermal comfort. The building did not score as well as the ILC in the Sustainable Sites section because it will be built on a site that has not previously been developed. The final scorecard can been seen in Appendix N. The building received 66 points for a LEED gold rating.

Table 43: Overview of LEED Score

Category	**Points Awarded**	**Possible Points**
Sustainable Sites	16	26
Water Efficiency	8	10
Energy and Atmosphere	21	35
Materials and Resources	4	14
Indoor Environmental Quality	12	15
Innovation and Design Process	3	6
Regional Priority Credits	2	4
Total	66	110

5.4 Energy Simulation

An energy analysis is a useful tool for estimating the energy use and operating cost of a building. There are many different mediums to perform an energy analysis. The design team opted to run an energy simulation in Revit. The energy analysis in Revit provides useful data such as energy use intensity and lifecycle cost. Specifically, it predicts the electricity and fuel usage per square foot throughout a single year. The energy analysis breaks down how the fuel and electricity is distributed and the costs associated with them. It also breaks down the heating and cooling load and highlights peak months. A summary of the energy analysis can be found below in Table 44, and the full results for the AREN building can be seen in Appendix O.

Table 44: Energy Analysis Summary Table

Annual Energy Use	
HVAC	19,780 Therms
Domestic Hot Water	2,693 Therms
Annual Electricity Use	
HVAC	120,848 kWh
Lighting	84,956 kWh
Misc. Equipment	90,739 kWh

The energy analysis shows how the building allocates half its energy use to electricity, and the other half to fuel. However, electricity is much more expensive. As seen in Figure 39, the HVAC system, lighting, and miscellaneous equipment all make noticeable contributions to the electricity usage. The fuel usage is mainly controlled by the HVAC system. The energy analysis also provides diagrams presenting fuel consumption by month. All of this information is useful because it highlights how energy is being used and where reductions can be made if necessary.

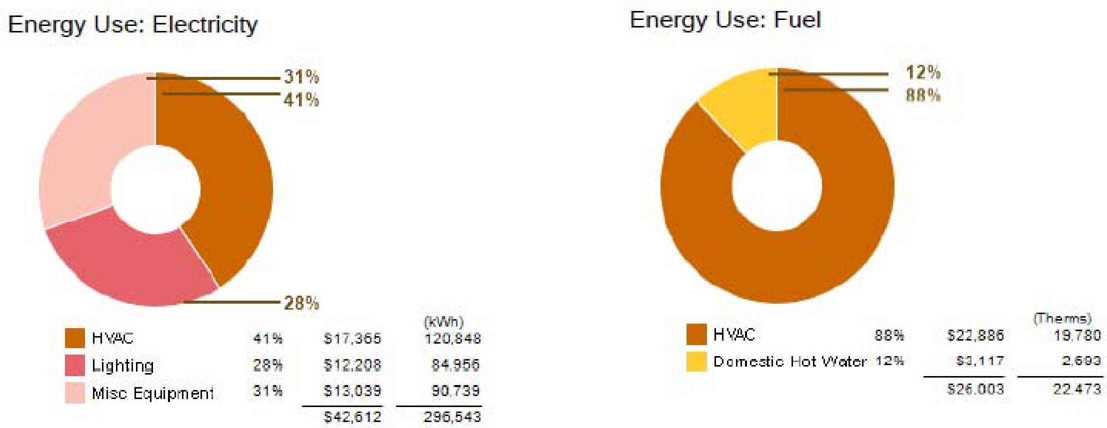


Figure 39: Energy Use

The energy analysis is conducted using several building performance factors. One factor is location, which influences the outdoor air temperature factor. Another factor is the electricity fuel cost, which is also relative to location. The energy analysis relies heavily on the thermal properties of the building materials in the model, making the energy simulation convenient to analyze various materials. A building designer could simulate how two different materials perform, thus, affecting energy use and cost. For example, the designer could simulate a building using two different glass manufacturers for a curtain wall or could change the structure of the wall to see how brick compares thermally to terracotta panels. In addition, the designer could test the benefit of using three inches of insulation as opposed to two. If a designer or owner is considering making changes to a building to improve performance and efficiency, energy simulation could be used to accurately determine if the changes are worthwhile. The data from the energy analysis is summarized below in Table 44.

5.5 Cost Estimate

There are multiple techniques used to determine the cost of a building. The two methods utilized for this project are square footage costs from RSMeans data and a combination of material take-off using AutoDesk Revit with the assembly costs from the RSMeans data.

5.5.1 RSMeans Square Footage Costs

The first method uses costs per square foot of area based on the building parameters and years of data collected by RSMeans. The data below was collected from the *2016 RSMeans Square Foot Costs* in the Green Commercial/Industrial/Institutional category. The building selected as reference was “G.120, G College, Classroom, 2-3 Story” due to the design goal of an energy efficient building. Various adjustments are needed for additional stories, story height, perimeter differences, and location of the building. The cost estimate based on square footage data can be found below in Table 45.

Table 45: Square Footage Cost Estimate

	Cost ($/sf)	Total Cost ($)
Second, Third, Fourth Floors (34,485 Square Feet)		
Base Square Footage Cost	$ 216.03	
Perimeter Adjustment	$ -3.08	
Story Height Adjustment		
Second Floor	$ 3.43	
Third Floor	$ 18.00	
Fourth Floor	$ 18.00	
Cost Per Square Foot	$ 238.86	$ 8,237,000
Basement (6,724 Square Feet)		
Basement Base Square Footage Cost	$ 44.48	
Basement Story Height Adjustment	$ 3.43	
Basement Cost Per Square Foot	$ 47.91	$ 299,109.60
Additives		
Elevator		$ 84,550
Seating		
100-Person Lecture Hall		$ 30,000
200-Person Lecture Hall		$ 60,000
30-, 35-, 40-, 40-Person Classrooms		$ 14,500
Three 25-Person Studios		$ 11,250
Sound Systems		$ 21,753
Total Cost		
Total Cost:		$ 8,758,000
Location Factor	1.1	
Total Adjusted Cost:	$ 233.79	**$ 9,634,000**

5.5.2 Material Take-Off

The second method used to calculate an estimated cost of the building is the Material Take-Off feature in Revit. This method utilizes Revit to calculate the number or area of each component of the model such as the total wall square footage, the number of lights, and more. The output from Revit can then be multiplied by the assembly costs provided by *2016 RSMeans Square Footage Cost*. The assemblies provide unit costs for specific building components that can be used for a more detailed cost breakdown, as seen below in Table 46.

Table 46: Material Take-Off Cost Analysis

Family	Type	Amount	Unit	Unit Cost	Total Cost
AHU-Rooftop-Carrier-Gas Heated	20-60 ton-WeatherMaker 48A-020	41209	SF	$12.85	$ 529,535.65
Basic Roof - Steel Truss, Metal Deck	EPDM with Insulation	51583	SF	$4.64	$ 239,345.12
Basic Wall	Core Wall	31361	SF	$24.84	$ 779,007.24
Basic Wall	Fire Stair Walls	804	SF	$14.13	$ 11,360.52
Basic Wall	Interior Walls	61924	SF	$5.78	$ 357,920.72
Basic Wall	MQP Exterior Brick Wall	84696	SF	$32.08	$ 2,717,047.68
Bradley Corp-Laminate Urinal Screen	11" x 42" Urinal Screen	12	EA	$373.00	$ 4,476.00
Bradley Corp-Laminate-ADA-N Stalls	ADA (optional) + n Standard Stalls	40	EA	$2,535.00	$ 101,400.00
Bradley Corp-Laminate-N Stalls	n Standard Stalls	16	EA	$2,535.00	$ 40,560.00
Compound Ceiling	2' x 2' ACT System	34339	SF	$4.23	$ 145,253.97
Curtain Wall - Glazing	Schueco 38mm glazing, triple	6610	SF	$23.25	$ 153,682.50
Curtain Wall - Spandrel	Schueco 38mm Panel	689	SF	$28.00	$ 19,292.00
Door-Curtain-Wall-Double-Glass	Door-Curtain-Wall-Double-Glass	8	EA	$6,175.00	$ 49,400.00
Door-Double-Glass	72" x 84"	12	EA	$6,175.00	$ 74,100.00
Door-Exterior-Revolving-Full Glass-Metal	84" x 84"	1	EA	$41,000.00	$ 41,000.00
Door-Passage-Double-Flush	72" x 84"	12	EA	$1,252.00	$ 15,024.00
Door-Passage-Single-Full Lite	36" x 84"	24	EA	$626.00	$ 15,024.00
Door-Passage-Single-Vision Lite	36" x 84"	51	EA	$626.00	$ 31,926.00
Door-Passage-Single-Vision Lite	48" x 84"	8	EA	$626.00	$ 5,008.00
Elevator	2500 Front	1	EA	$91,550.00	$ 91,550.00
Floor	Carpet	13636	SF	$4.45	$ 60,680.20
Floor	Lobby Floor	15192	SF	$5.13	$ 77,934.96
Floor	Slab - 5"	66752	SF	$6.82	$ 455,248.64
Floor	Slab on Grade - 5"	6742	SF	$6.82	$ 45,980.44
Floor	Wooden Floor	5511	SF	$5.40	$ 29,759.40
Lighting Downlight	Cooper-Portfolio-LDSQA4A	16484	SF	$2.56	$ 42,198.02
Lighting Troffer	Metalux-ArcLine-22ALN-24ALN-LED-LD4	24725	SF	$2.71	$ 67,005.83

Structural Steel Columns	ASTM A992				$ 74,006.28
Structural Steel Framing	ASTM A992	34485	SF	$11.95	$ 412,095.75
Toilet-Commercial-Wall-3D	15" Seat Height	22	EA	$2,005.00	$ 44,110.00
Urinal-Wall-3D	Urinal-Wall-3D	5	EA	$1,405.00	$ 7,025.00
Wall Foundation	Foundation - 12" Concrete	1159	LF	$128.00	$ 148,352.00
Wall Foundation	Foundation Wall - 6"	1498	LF	$128.00	$ 191,744.00
Wall Foundation - Strip Footings	Bearing Footing - 24" x 8"	638.5	LF	$41.15	$ 26,274.28
Wall Foundation - Strip Footings	Bearing Footing - 24" x 12"	1101.5	LF	$41.15	$ 45,326.73
	Total Cost				$ 7,149,654.92
	Sales Tax			6%	$ 428,979.29
	General Requirements			7%	$ 500,475.84
	Overhead			5%	$ 357,482.75
	Profit			5%	$ 357,482.75
	Architect Fees			8%	$ 571,972.39
	Location Factor			10%	$ 714,965.49
	Final Cost				**$ 10,081,013.43**

5.5.3 Cost Comparison

While the square footage and material take-off methods provide comparable estimates, there are still factors that cannot be accounted for in the generalizations of the RSMeans data. To determine if these estimates are realistic, data from *Learning by Design* magazine and local university projects were consulted and summarized in the following Table 47 and Figure 40.

Table 47: Square Footage Cost Comparison

University	**Location**	**Location Factor**	**Square Footage**	**Cost per psf**	**Adjusted Cost**
Northwest Nazarene U - Riley Library	Nampa, ID	0.91	57800	$156	$171
Xavier	Cincinnati, OH	0.92	63000	$202	$220
Colorado Mesa U - Garfield Residence	Grand Junction, CO	0.93	98512	$203	$218
U of Washington - Student Center	Tacoma, WA	1.01	70238	$209	$207
U of Arkansas - Fort Smith	Fort Smith, AR	0.82	57000	$236	$288
U of Hawaii at Manoa - Sakamaki	Honolulu, HI	1.23	23648	$300	$244
Belmont U - R Milton and Denice Johnson	Nashville, TN	0.88	135034	$407	$463
The Egg - Culinary Institute	Hyde Park, NY	1.16	39127	$499	$430
Foisie Innovation Studio (WPI)	Worcester, MA	1.10	78000	$481	$437
Clark University Alumni & Student Center	Worcester, MA	1.10	36000	$472	$429
		Average	**65836**	**$317**	**$311**
Architectural Engineering Building (WPI)	Worcester, MA	1.10	41209	$240	$218

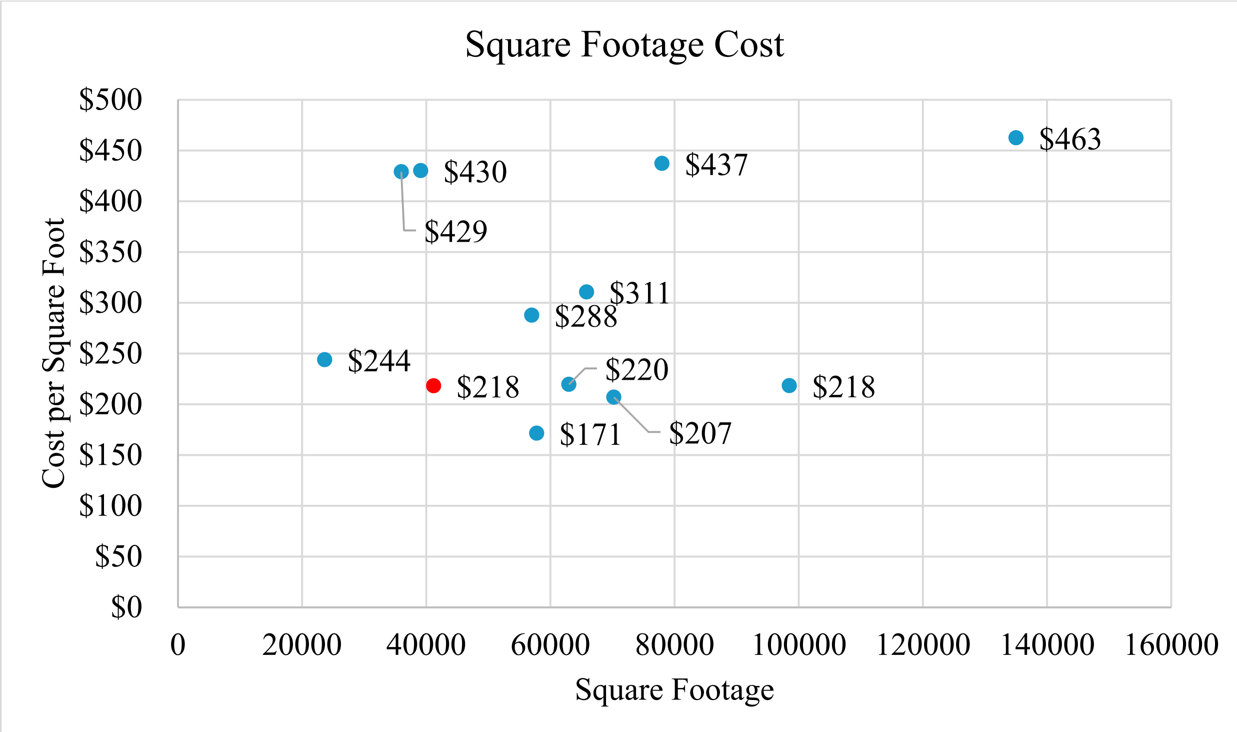


Figure 40: Square Footage Cost Data (with WPI Architectural Engineering Building in Red)

According to this data, the Architectural Engineering Building has a lower cost compared to similar buildings in Worcester, MA. However, the calculated cost of the new building only includes rough estimates of some things that would be needed such as removable furnishings, fire protection systems, and telecommunication systems. Further cost analysis would be needed on the additional plumbing, electrical, and any additional furniture to be added. The additional cost of these services could raise the square footage cost of the building closer to $300 per square foot. However, as this building does not require any equipment for laboratories, residences, or other specialty uses as the other buildings in Worcester, MA do, it is unlikely the cost of the building would near the $400 per square foot cost of the other Worcester, MA buildings.

5.5.4 Cost Breakdown

The cost of the project is divided into the seven UNIFORMAT II categories: Substructure, Shell, Interiors, Services, Equipment and Furnishings, Special Construction and Building Sitework. However, the *RSMeans Square Foot Cost* data does not include the cost of Building Sitework as that is often not included in the building cost. This building does not contain any Special Construction so the first five categories were included in the cost breakdown. Each category makes up 11%, 52%, 22%, 12% and 3% respectively as seen below in Figure 41.

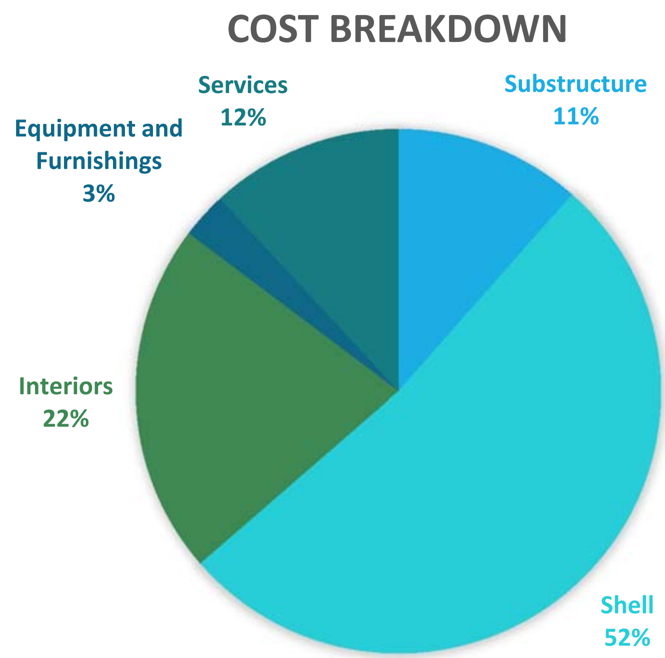


Figure 41: Cost Breakdown

The *RSMeans Square Foot Costs* data for a G.120 building indicates that the breakdown should be 3.6%, 18.7%, 28.3%, 50.4% and 0.1%. The comparison between this building and the *RSMeans Square Foot Costs* G.120 building can be seen below in Table 48 as well as a range of other similar academic buildings.

Table 48: Cost Breakdown Comparison

	Architectural Engineering Building	**RSMeans G.120**	**Range of Academic Buildings**
Substructure	11%	3.6%	4.0%-8.0%
Shell	52%	18.7%	24.4%-32.3%
Interiors	33%	28.3%	18.5%-22.8%
Services	12%	50.4%	40.1%-48.8%
Equipment and Furnishings	3%	0.1%	0%-9.1%

The G.120 building Substructure includes shorter foundation walls and a thinner slab on grade than this building. The shell of the G.120 building consists of concrete block and only 54 windows, leading to a much lower cost percentage for the Shell of the building. The interior cost percentages of both buildings are relatively similar based on similar construction types and assemblies. The Services percentage of the G.120 building is much greater than that of this building. This discrepancy is likely due to the lack of complete plumbing, fire protection, and electrical systems in the Architectural Engineering building estimate. These system total 45.7% of the estimated G.120 cost. Lastly, the Equipment & Furnishings of the G.120 building are only 0.1% due to the only moveable furniture included being waste handling bins and no smoking signage. While the values for the Architectural Engineering building differ from the G.120 values, this is to be expected as the G.120 is simply an example of a single building with certain characteristics. However, the breakdown of the cost of the Architectural Engineering building aligns with the focuses of this project that are most accurately represented in the cost estimate.

The *RSMeans Square Foot Cost* analysis provided a cost estimate of $9,634,053.48, and the Material Take-Off analysis provided a cost estimate of $10,081,013.43. These estimates provide data that lead to a final cost estimate of approximately $10 million for this building.

5.6 Schedule

In order to begin a construction schedule, it was necessary for the design team to determine the start and end dates for the defined project. Once the dates were defined, the activities necessary to complete the construction of the academic building were identified and arranged in a logical production sequence.

For the construction of an academic building, the Construction Specifications Institute (CSI) classification system was referenced. The CSI provided foundational knowledge about the construction process and the variety of activities that are involved in erecting a building. There are two formats within the CSI system, the Uniformat for design and the Masterformat for construction. Masterformat has had many problems adjusting to advancing technology and has had difficulty in characterizing each activity with material versus functional organization. Uniformat is an alternative classification system based more consistently on general system and was chosen by the design team to organize construction activities.

The design team referenced the ASTM Uniformat II Classification for Building Elements, below as Table 49, for an overall reference for the breakdown of building levels. There are three Major Group Elements broken down by Level 1, Level 2, and Level 3.

Table 49: ASTM Uniformat II

Level 1 **Major Group Elements**	**Level 2** **Group Elements**	**Level 3** **Individual Elements**
Substructure	Foundations and Basement Construction	Standard Foundations, Special Foundations, Slab on Grade, Basement Excavation, Basement Walls
Shell	Superstructure, Exterior Closure, and Roofing	Floor Construction, Roof Construction, Exterior Walls, Exterior Windows, Exterior Doors, Roof Coverings, Roof Openings
Interiors	Interior Construction, Staircases, and Interior Finishes	Partitions, Interior Doors, Specialties, Stair Construction, Stair Finishes, Wall Finishes, Floor Finishes, Ceiling Finishes

Services	Conveying Systems, Plumbing, HVAC, Fire Protection, Electrical	Elevators, Escalators and Moving Walks, Material Handling Systems, Plumbing Fixtures, Domestic Water Distribution, Sanitary Waste, Rain Water Drainage, Special Plumbing Systems, Energy Supply, Heat Generating Systems, Cooling Generating Systems, Distribution Systems, Terminal & Package Units, Controls and Instrumentation, Special HVAC Systems and Equipment, Systems Testing and Balancing, Fire Protection Sprinkler Systems, Stand-Pipe and Hose Systems, Fire Protection Specialties, Special Electrical Systems, Electrical Service Distribution, Lighting and Branch Wiring, Communications and Security Systems, Special Electrical Systems
Equipment and Furnishings	Equipment and Furnishing	Commercial Equipment, Institutional Equipment, Vehicular Equipment, Other Equipment, Fixed Furnishings, Moveable Furnishings
Special Construction and Demolition	Special Construction and Selective Building Demolition	Special Structures, Integrated Construction, Special Construction Systems, Special Facilities, Special Controls and Instrumentation, Building Elements Demolition, Hazardous Components Abatement

Within these three levels are eight major group elements: General Conditions, Site Work, Substructure, Shell, Interiors, Services, Equipment and Furnishings, and Special Construction and Demolition. These broad group elements helped the design team plan out specific construction steps.

While this construction activity breakdown was being assembled, similar construction projects within Worcester were examined and referenced to identify elements applicable to the construction of this academic building. Additionally, construction simulation videos of other buildings on campus, such as the Sports and Recreation Center and East Hall, were reviewed to determine durations of activities. These simulation videos depicted the process of construction from beginning to end and aided the design team in listing out the required stages.

However, for activities with high levels of design detail, specifically the erection of structural steel, a calculation was performed to estimate a more specific duration for the activity. According to *2016 RSMeans for Construction Costs*, per crew of eight workers working a total of 64 hours per workday, one linear foot of steel can be erected for 0.125 labor hours. This calculation helped the design team determine that eight linear feet per crew member per labor hour can be performed during the construction process. With eight linear feet per labor hour multiplied by the 64 labor hours per day, a total of 512 linear feet of steel can be erected per day. This academic building was designed with 215 steel members of various lengths, summing to 34,485 square feet of structural steel with an average of 4,300 linear feet of steel per segment. By dividing the 4,300 linear feet of steel by the 512 linear feet of steel that can be erected each workday, the design team determined that each steel segment will take approximately 8 days to erect.

Based on the productivity rates, the design team was able to determine specific activity durations for each section of the steel that needed to be erected. The duration for the Site Prep and Foundation activities during the project was determined by building simulation videos taken on the WPI campus as referenced above. The Enclosure, Services, and Furnishing activities were estimated by the East Hall project schedule. While references served the design team to be reliable sources, each individual construction project is different and therefore might challenge the duration of an activity specific to the design of the AREN building.

The program Microsoft Project was used to organize the scheduled construction activities for the production of the AREN building. The starting date for the project was determined to be May 15, 2017, so WPI commencement could happen without any interferences. Once all the construction activities are completed, and if everything remains on schedule, the expected finish date for this project is December 6th, 2018. Appendix P displays the complete Microsoft Project output for each construction activity, its duration, and beginning and end dates.

6 Conclusion

The overarching goal of this project was to meet the growing need for more academic space on the WPI campus, especially for the Architectural Engineering department. With the consistent increase of students accepted and enrolled at WPI, and therefore the growth of the AREN department, there is a strong need for more space for students to gather and achieve academic success. To promote WPI's flexible learning approach to group collaboration, a new academic building was proposed to provide students and faculty with additional space to learn and collaborate in a project-based setting.

This project meets the goals set forth in the initial states of the design. These achieved goals include:

1. Develop an architectural design
2. Develop a structural design and analysis
3. Develop a mechanical design and analysis
4. Develop a fire protection design and analysis
5. Perform an energy analysis and LEED Accreditation
6. Develop a cost analysis and project schedule

The project meets these goals by including spreadsheets, documents, and floor plans for architectural, structural, mechanical, and fire protection designs. The design team exemplified an extensive understanding of how a building must be designed and coordinated during the timeframe of this project. Once the building was designed, a cost analysis and construction schedule were developed. Additionally, an energy analysis and LEED Evaluation were performed.

The scope of the work required to complete this project included the architectural, structural, and mechanical concepts and designs for the proposed academic building. Intensive coordination between disciplines was necessary for a successful building design.

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Appendix A - Lighting Specifications

Metalux

Catalog #		Type
Project		
Comments		Date
Prepared by		

DESCRIPTION

ArcLine is a premium grade specification lensed troffer series. This innovative, high quality luminaire is dedicated to the latest solid state lighting and driver technology for optimal performance and energy efficiency. The ArcLine is compatible with all of today's popular ceiling systems and is available with a number of options and accessories for application versatility.

The ArcLine series features efficiency, quality and performance. The series is an excellent choice for commercial office spaces, schools, hospitals or retail merchandising areas.

SPECIFICATION FEATURES

Construction
Rigid housing is die formed of code gauge prime cold rolled steel and features full length die-formed stiffeners and unibody endplate for added strength. Side flanges are hemmed. Innovative design provides superior lens brightness uniformity and visual comfort. Unibody endplates are securely attached with interlocking tabs and screws. Four auxiliary fixture end suspension points provided. Ample KOs are provided for continuous row wiring. Endplates have integral Grid-lock feature for safety and convenience.

Controls
The ArcLine LED is Powered by Fifth Light, with a standard 0-10V continuous dimming driver that works with any 0-10V control/ dimmer. Combine with energy saving products like occupancy sensors, daylighting controls and lighting relay panels to maximize energy savings. In addition, the ArcLine can include a factory-installed integrated sensor system for occupancy and daylight dimming control and manual control from an optional handheld remote. Or, specify the Digital

Addressable Lighting Interface (DALI) drivers, dimmable down to 10%, for use with Fifth Light controls. See ordering information for details on all three options.

Electrical
Long-Life LED system coupled with electrical driver to deliver optimal performance. LED's available in 3000k, 3500k or 4000k with a CRI ≥ 85. Projected life is 60,000 hours at 86% lumen output. cULus listed. Electronic drivers are available for 120-277V applications.

Emergency Battery Pack Option
Optional 120v-277v integral emergency battery pack is available in 7-watts or 14-watts to meet critical life-safety lighting requirements. The 90-minute batteries provide constant power to the LED system, ensuring code-compliance. A test switch/indicator button can be tested safely from the ground using a laser pointer, while the patented EZ Key prevents accidental discharge of the battery during construction. See ordering information for details.

Finish
Multistage, iron phosphate pretreatment ensures maximum

bonding and rust inhibition. Housing and ballast cover finished with new 90% reflective white enamel for superior performance.

Hinging/Latching
Positive cam action steel latches with baked white enamel finish. Safety-lock T-hinges allow hinging and latching either side. Door assembly hinges down for easy access from below without tools.

Frame/Sheilding
Die formed, heavy gauge, flat steel door with reinforced mitered corners and painted after fabrication, baked matte white enamel finish. Positive light seals. Acrylic frosted lens.

Compliance
Modules are UL recognized components and indoor luminaires are cULus listed for 25ºC ambient environments, RoHS compliant, and LED modules comply with IESNA LM-79 and LM-80 standards. DesignLights Consortium™ Qualified and classified for DLC Standard, refer to www. designlights.org for details.

Warranty
Five year warranty.

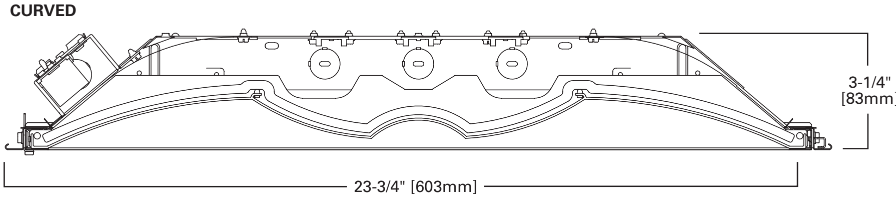
24ALN
LED

2' X 4' TROFFER LED MODULE

Specification Grade Troffer
Curved Shielding

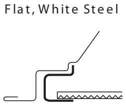
powered by fifthlight technology

CURVED

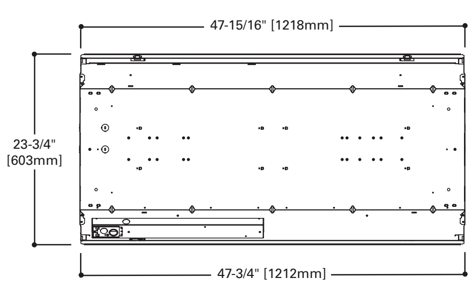


DOOR FRAMES

ALN
Flat, White Steel



MOUNTING DATA



CERTIFICATION DATA

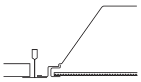
cULus1598
Damp Location Listed
IC Rated
LM79/LM80 Compliant
ROHS Compliant
DesignLights Consortium™ Qualified

LINEAR DISCONNECT
Safe and convenient means of disconnecting power

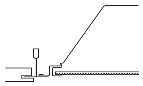
EATON
Powering Business Worldwide

CEILING COMPATIBILITY

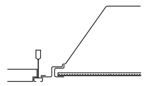
G
Grid/Lay-in
Standard



G
Concealed T



G
Slot Grid



Ceiling Type	Trim Type
Exposed Grid	G
Concealed T	G
Slot Grid	G

(Verify compatibility/ consult factory.)

ENERGY AND PERFORMANCE DATA BY CATALOG NUMBER

Stock or MTO*	Catalog Logic (Curved Shielding)	Delivered Lumens	Watts	Efficacy (lm/W)
MTO	24ALNG-LD4-31-UNV-L830-CD1-U	2782	25.6	109
MTO	24ALNG-LD4-31-UNV-L835-CD1-U	3029	25.6	118
MTO	24ALNG-LD4-31-UNV-L840-CD1-U	3192	25.6	125
MTO	24ALNG-LD4-36-UNV-L830-CD1-U	3358	31.7	106
MTO	24ALNG-LD4-36-UNV-L835-CD1-U	3656	31.7	115
MTO	24ALNG-LD4-36-UNV-L840-CD1-U	3852	31.7	122
MTO	24ALNG-LD4-42-UNV-L830-CD1-U	3789	36.4	104
MTO	24ALNG-LD4-42-UNV-L835-CD1-U	4126	36.4	113
MTO	24ALNG-LD4-42-UNV-L840-CD1-U	4348	36.4	119
MTO	24ALNG-LD4-45-UNV-L830-CD1-U	4254	41.8	102
STOCK	24ALNG-LD4-45-UNV-L835-CD1-U	4632	41.8	111
STOCK	24ALNG-LD4-45-UNV-L840-CD1-U	4881	41.8	117
MTO	24ALNG-LD4-50-UNV-L830-CD1-U	4715	47.6	99
MTO	24ALNG-LD4-50-UNV-L835-CD1-U	5134	47.6	108
MTO	24ALNG-LD4-50-UNV-L840-CD1-U	5409	47.6	114
MTO	24ALNG-LD4-55-UNV-L830-CD1-U	5111	50.9	100
STOCK	24ALNG-LD4-55-UNV-L835-CD1-U	5565	50.9	109
STOCK	24ALNG-LD4-55-UNV-L840-CD1-U	5864	50.9	115
MTO	24ALNG-LD4-60-UNV-L830-CD1-U	5584	56.7	98
MTO	24ALNG-LD4-60-UNV-L835-CD1-U	6080	56.7	107
MTO	24ALNG-LD4-60-UNV-L840-CD1-U	6406	56.7	113
MTO	24ALNG-LD4-67-UNV-L830-CD1-U	6206	64.6	96
MTO	24ALNG-LD4-67-UNV-L835-CD1-U	6758	64.6	105
MTO	24ALNG-LD4-67-UNV-L840-CD1-U	7121	64.6	110
MTO	24ALNG-LD4-74-UNV-L830-CD1-U	6832	73.2	93
MTO	24ALNG-LD4-74-UNV-L835-CD1-U	7439	73.2	102
MTO	24ALNG-LD4-74-UNV-L840-CD1-U	7838	73.2	107
MTO	24ALNG-LD4-80-UNV-L830-CD1-U	7411	82.2	90
MTO	24ALNG-LD4-80-UNV-L835-CD1-U	8070	82.2	98
MTO	24ALNG-LD4-80-UNV-L840-CD1-U	8503	82.2	103

*Made to order (MTO) requires a typical four week lead time.

LUMEN MAINTENANCE

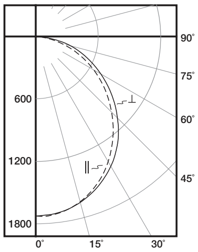
Ambient Temperature	TM-21 Lumen Maintenance (60,000 hours)	Theoretical L70 (Hours)
25°C	> 86%	> 144,000

Powering Business Worldwide

Eaton
1121 Highway 74 South
Peachtree City, GA 30269
P: 770-486-4800
www.eaton.com/lighting

Specifications and dimensions subject to change without notice.

PHOTOMETRICS



24ALNG-LD4-45-UNV-L835-CD1-U

Electronic Driver

Linear LED 3500K

Spacing criterion: (II) 1.2 x mounting height, (⊥) 1.2 x mounting height

Lumens: 4632

Input Watts: 41.8W

Efficacy: 110.8 lm/W

Test Report: 24ALNG-LD4-45-UNV-L835-CD1-U.IES

Candlepower

Angle	Along II	45°	Across ⊥
0	1724	1724	1724
5	1721	1718	1714
10	1690	1690	1689
15	1639	1642	1646
20	1569	1578	1588
25	1484	1498	1516
30	1381	1406	1433
35	1267	1302	1335
40	1147	1192	1225
45	1020	1069	1099
50	892	941	974
55	764	810	844
60	634	681	713
65	504	557	586
70	378	435	463
75	253	319	343
80	141	206	208
85	52	86	79
90	0	0	0

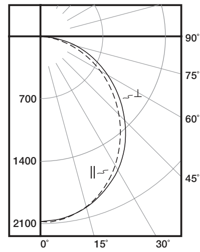
Coefficients of Utilization

Effective floor cavity reflectance 20%

rc	80%				70%				50%			30%			10%			0%
rw	**70**	**50**	**30**	**10**	**70**	**50**	**30**	**10**	**50**	**30**	**10**	**50**	**30**	**10**	**50**	**30**	**10**	**0**
RCR																		
0	119	119	119	119	116	116	116	116	111	111	111	106	106	106	102	102	102	100
1	109	104	100	96	106	102	98	94	97	94	91	94	91	88	90	88	86	84
2	99	91	84	78	96	89	83	77	85	80	75	82	78	74	79	75	72	70
3	90	80	72	65	88	78	71	64	75	69	63	72	67	62	70	65	61	59
4	83	71	62	55	80	69	61	55	67	60	54	65	58	53	62	57	53	50
5	76	63	54	48	74	62	54	47	60	53	47	58	52	46	56	50	46	44
6	70	57	48	42	68	56	48	42	54	47	41	53	46	41	51	45	40	38
7	65	52	43	37	64	51	43	37	49	42	36	48	41	36	47	41	36	34
8	61	47	39	33	59	47	39	33	45	38	33	44	37	32	43	37	32	30
9	57	43	35	30	55	43	35	30	42	35	29	41	34	29	40	34	29	27
10	53	40	32	27	52	40	32	27	39	32	27	38	31	27	37	31	27	25

Zonal Lumen Summary

Zone	Lumens	% Fixture
0-30	1315	28.4
0-40	2128	45.9
0-60	3669	79.2
0-90	4632	100.0
0-180	4632	100.0



24ALNG-LD4-55-UNV-L835-CD1-U

Electronic Driver

Linear LED 3500K

Spacing criterion: (II) 1.2 x mounting height, (⊥) 1.2 x mounting height

Lumens: 5565

Input Watts: 50.9W

Efficacy: 109.3 lm/W

Test Report: 24ALNG-LD4-55-UNV-L835-CD1-U.IES

Candlepower

Angle	Along II	45°	Across ⊥
0	2069	2069	2069
5	2066	2061	2056
10	2028	2026	2024
15	1969	1970	1974
20	1885	1893	1902
25	1780	1797	1816
30	1659	1687	1720
35	1523	1562	1603
40	1381	1427	1469
45	1230	1281	1322
50	1075	1129	1172
55	920	974	1016
60	763	820	860
65	606	671	707
70	454	524	560
75	302	384	413
80	170	249	251
85	64	102	96
90	0	0	0

Coefficients of Utilization

Effective floor cavity reflectance 20%

rc	80%				70%				50%			30%			10%			0%
rw	**70**	**50**	**30**	**10**	**70**	**50**	**30**	**10**	**50**	**30**	**10**	**50**	**30**	**10**	**50**	**30**	**10**	**0**
RCR																		
0	119	119	119	119	116	116	116	116	111	111	111	106	106	106	102	102	102	100
1	109	104	100	96	106	102	98	94	97	94	91	94	91	88	90	88	86	84
2	99	91	84	78	96	89	83	77	85	80	75	82	78	74	79	75	72	70
3	90	80	72	65	88	78	71	64	75	69	63	72	67	62	70	65	61	59
4	83	71	62	55	80	69	61	55	67	60	54	65	58	53	62	57	53	50
5	76	63	54	48	74	62	54	47	60	53	47	58	51	46	56	50	46	44
6	70	57	48	42	68	56	48	41	54	47	41	53	46	41	51	45	40	38
7	65	52	43	37	64	51	43	37	49	42	36	48	41	36	47	41	36	34
8	61	47	39	33	59	47	38	33	45	38	33	44	37	32	43	37	32	30
9	57	43	35	30	55	43	35	30	42	34	29	41	34	29	40	34	29	27
10	53	40	32	27	52	40	32	27	39	32	27	38	31	27	37	31	27	25

Zonal Lumen Summary

Zone	Lumens	% Fixture
0-30	1577	28.3
0-40	2553	45.9
0-60	4406	79.2
0-90	5565	100.0
0-180	5565	100.0

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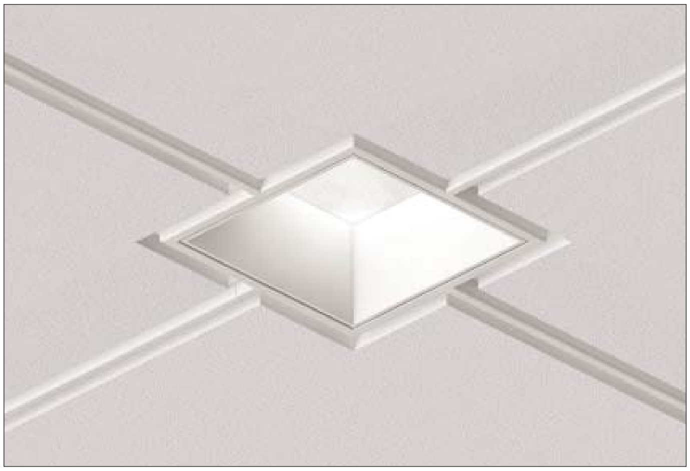
USAI® Lighting

BeveLED® Connect™ Downlight — C4SBD-CT

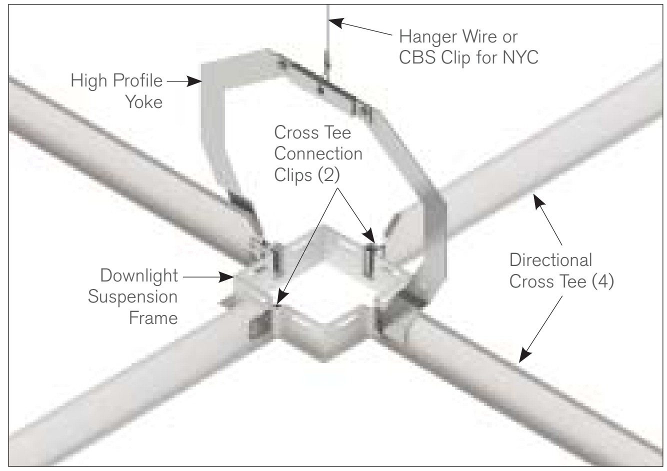
FOR USE WITH ARMSTRONG® 4" INTERSECTION DOWNLIGHTING KITS

BEVELED® CONNECT™ DOWNLIGHT



usailighting.com/connect

ARMSTRONG® INTERSECTION DOWNLIGHTING KIT



armstrongceilings.com/downlight

USAI Lighting and Armstrong Ceiling Solutions have partnered to offer architects and designers a new way to seamlessly integrate recessed downlights with architectural suspension systems. For the first time, LED downlights can be placed at the intersection of the ceiling grid– allowing for perfect alignment of lighting and architecture.

FEATURES

- Designers specify completely custom configurable or standard Armstrong® Intersection Downlighting kits and Calla® notched ceiling panels
- Contractors receive pre-cut factory finished panels for consistent fit and finish and easy installation
- USAI Connect simply snaps into place after installation of Armstrong® grid; no field painting or modification
- Industry leading illumination and craftsmanship
- Full family of downlight, adjustable, and wall wash light fixtures
- Seismically tested for use in D, E, F areas

BEVELED CONNECT DOWNLIGHT PERFORMANCE DATA

LED COLOR CHOICES

DELIVERED* PERFORMANCE:	Classic White 14W	Classic White 20W	Warm Glow Dimming 12W	Warm Glow Dimming 18W	Color Select 12W	Color Select 18W
Source Lumens:	1100	1500	900	1200	925	1200
Lumens Per Watt:	64	53	52	46	58	52
Delivered Lumens:	900	1150	650	850	700	925

*Performance data based on 3000K, 80+ CRI

CORRELATED COLOR TEMPERATURE	Classic White 2700K	Classic White 3000K	Classic White 3500K	Classic White 4000K	Warm Glow Dimming 2700K	Warm Glow Dimming 3000K	Warm Glow Dimming 3500K	Color Select 2200K	Color Select 2700K	Color Select 3000K	Color Select 3500K	Color Select 4000K	Color Select 5000K	Color Select 6000K
Color Rendering Index:	80+ 90+	80+ 90+	80+	80+	80+ 90+	80+ 90+	80+	80+	80+	80+	80+	80+	80+	80+
Multiplier for Lumen Output:	1.00 0.73	1.00 0.80	1.15	1.07	0.93 0.74	1.00 0.80	1.05	0.92	0.97	1.00	1.03	1.05	1.10	1.13

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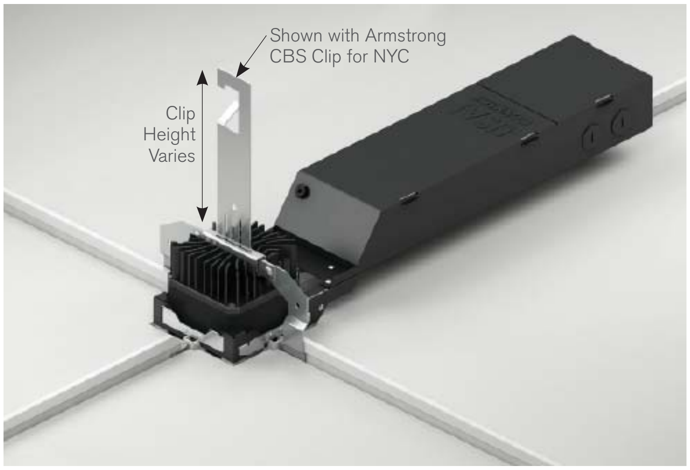
Patents pending. USAI, BeveLED, Color Select, Color Harmony and Warm Glow are registered trademarks of USAI, LLC.

USAI® Lighting

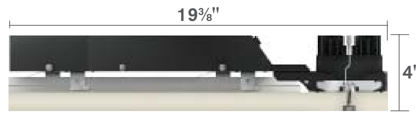
BeveLED® Connect™ Downlight — C4SBD-CT

FOR USE WITH ARMSTRONG® 4" INTERSECTION DOWNLIGHTING KITS

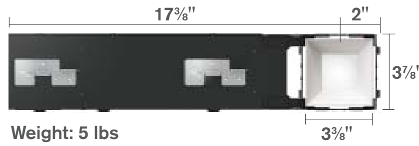


BeveLED® CONNECT™ shown with Armstrong® Intersection Downlighting Kit

CONNECT™ HOUSING FROM USAI

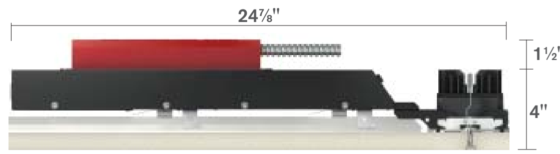


Alternate yoke for low plenum applications shown - Armstrong Ceilings Item#: FZD4YKLP
Standard yoke from Armstrong 8" height



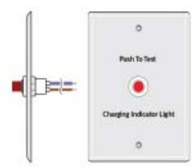
Weight: 5 lbs

Connect Housing - Shown with Emergency Battery

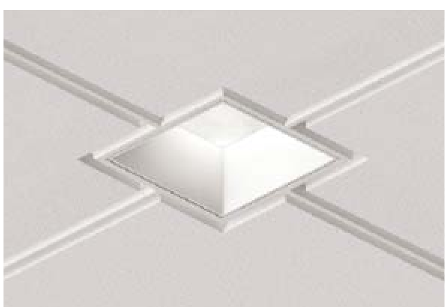


Weight: 8 lbs

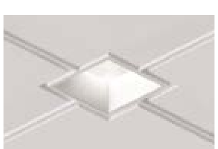
Remote Emergency Test Switch (included with EM Option)

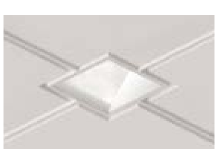


BEVELED® CONNECT™ DOWNLIGHT FOR INTERSECTION DOWNLIGHTING

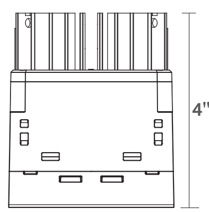

Downlight - C4SBD

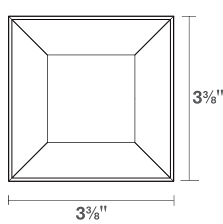
MORE BEVELED® CONNECT™ FAMILY TRIMS FOR INTERSECTION DOWNLIGHTING


Adjustable - C4SBA


Wall Wash - C4SBW

TRIM DIMENSIONS





RELATED PRODUCTS

SLIVERLED® CONNECT™ DOWNLIGHT FOR INTERSECTION DOWNLIGHTING


Downlight - C4SSD

TRUE ZERO® CONNECT™ DOWNLIGHT FOR INTERSECTION DOWNLIGHTING


Downlight - C4SZD

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BeveLED® Connect™ Downlight

Armstrong® CEILING SOLUTIONS

USAI® Lighting

FOR USE WITH ARMSTRONG® 4" INTERSECTION DOWNLIGHTING KITS

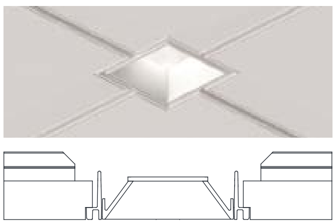
KEY SELECTION ATTRIBUTES

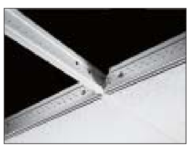
- Lighting and architecture perfectly integrated into the ceiling to deliver your vision of symmetry
- Replaces inconsistent finishes and edge details with clean crisp factory finished panels and grid for a fast and easy installation
- Eliminates the worry of field modified panels and grid
- For more information and how to specify compatible Armstrong® Suspension Systems go to: armstrongceilings.com/downlight

COMPATIBLE 9/16'' ARMSTRONG® SUSPENSION SYSTEMS

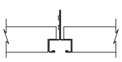
These pre-engineered suspension systems seamlessly integrate recessed downlights at the intersection of the ceiling grid - placing light where it has never been before.

Silhouette® 1/4" reveal

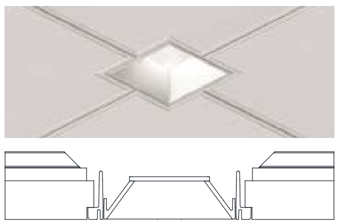




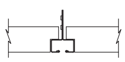
Detail



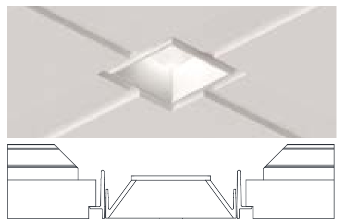
Silhouette® 1/8" reveal

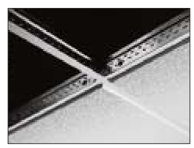


Detail

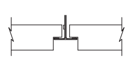


Suprafine® XL® reveal

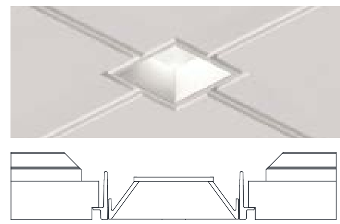




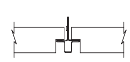
Detail



Interlude® XL® HRC reveal

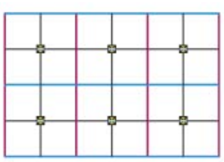


Detail

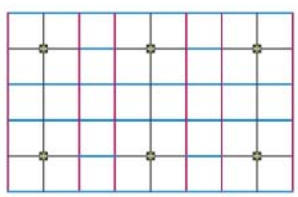


APPLICATION LAYOUT EXAMPLES WITH BEVELED® CONNECT™ DOWNLIGHT

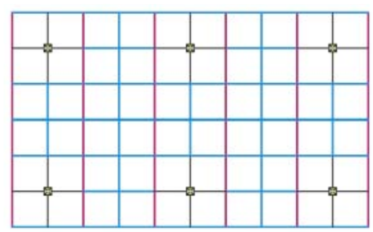
2' X 2' CEILING LAYOUT WITH LIGHTS 4' ON CENTER



2' X 2' CEILING LAYOUT WITH LIGHTS 6' ON CENTER



2' X 2' CEILING LAYOUT WITH LIGHTS 8' ON CENTER



KEY: ☒ Downlight Suspension Frame — Yoke — Main Beams — Directional Cross Tee — Cross Tees

4' x 4' LAYOUT	CEILING HEIGHT			
LIGHT LEVELS AT:	8'	10'	12'	14'
PERSON HEIGHT (5'AFF):	73	66	66	65
WORK PLANE (2.5' AFF):	67	66	65	64
FLOOR	67	66	65	64

Perfect for showrooms, retail applications, and examination areas

6' x 6' LAYOUT	CEILING HEIGHT			
LIGHT LEVELS AT:	8'	10'	12'	14'
PERSON HEIGHT (5'AFF):	37	33	32	31
WORK PLANE (2.5' AFF):	33	32	31	30
FLOOR	32	32	31	30

Ideal for open offices, private offices, conference rooms, restrooms, meeting spaces, and classrooms

8' x 8' LAYOUT	CEILING HEIGHT			
LIGHT LEVELS AT:	8'	10'	12'	14'
PERSON HEIGHT (5'AFF):	20	18	18	17
WORK PLANE (2.5' AFF):	19	18	17	17
FLOOR	18	17	17	17

Excellent for corridors, lobbies, circulation spaces, and lounge areas

NOTES: All illuminance values are average values, measured in footcandles (fc). All measurements for BeveLED Connect C4SBD, 20W, 50° beamspread.

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Appendix B - Lighting Calculations

Fourth Floor

		Room Area	Height	Perimeter	Length	Width	Room Cavity Ratio	Coefficient of Utilization	Luminaires /Fixture	Number of Fixtures	Lumens	Light Loss Factor	Footcandles	Watts	W/Room	W/Area	Lights	BTUH/Room	CFM
Room			**H**	**P**	**L**	**W**	**RCR**	**CU**	**n**	**N**	**F**	**LLF**	**E**	**W**			**BTUH**		
Tech Suite 1		164	10	-	15.667	10.5	8	0.52	1	2	5565	0.8	30	50.9	101.8	0.62	347.36	3467	168
Tech Suite 2		164	10	-	15.667	10.5	8	0.52	1	2	5565	0.8	30	50.9	101.8	0.62	347.36	3467	168
Tech Suite 3		158	10	-	15.667	10.08	8.1	0.47	1	2	5565	0.8	30	50.9	101.8	0.64	347.36	3467	168
Classroom 1		625	10	-	30.917	20.25	4.1	0.71	1	8	5565	0.8	40	50.9	407.2	0.65	1389.42	12588	605
Classroom 2		669	10	-	30.917	21.583	3.9	0.8	1	9	5565	0.8	40	50.9	458.1	0.68	1563.1	14011	673
Classroom 3		678	10	-	25	27.08	3.8	0.8	1	8	5565	0.8	40	50.9	407.2	0.6	1389.42	13838	665
Conference Room 1		306	10	-	12.583	24.5	6.1	0.57	1	6	5565	0.8	40	50.9	305.4	1	1042.07	6162	297
Conference Room 2		379	10	-	13.833	26.5	5.3	0.63	1	5	5565	0.8	40	50.9	254.5	0.67	868.39	5988	289
Lecture Hall 1		1136	10	-	32.583	34.833	3	0.91	1	11	5565	0.8	40	50.9	559.9	0.49	1910.46	29359	1407
Lecture Hall 2		1597	10	157	-	-	2.5	0.91	1	16	5565	0.8	40	50.9	814.4	0.51	2778.85	55227	2645
Storage Room		83	10	-	8.25	9.583	10.7	0.4	1	1	5565	0.8	20	50.9	50.9	0.61	173.68	174	11
Men's Bathroom		214	10	-	14.417	14.833	6.8	0.57	1	2	5565	0.8	18	50.9	101.8	0.48	347.36	347	19
Women's Bathroom		214	10	-	14.417	14.833	6.8	0.57	1	2	5565	0.8	18	50.9	101.8	0.48	347.36	347	19
Entrance		910	10	146	-	-	4	0.71	1	8	5565	0.8	28	50.9	407.2	0.45	1389.42	5139	248
Open Area		596	10	125.83	-	-	5.3	0.63	1	6	5565	0.8	28	50.9	305.4	0.51	1042.07	4792	232
Egress North		347	10	-	26	13.333	5.7	0.63	1	3	5565	0.8	25	50.9	152.7	0.44	521.03	521	27
Egress South		414	10	-	26.5	15.417	5.1	0.63	1	4	5565	0.8	25	50.9	203.6	0.49	694.71	695	36
East Hall		465	10		47					18	1500	0.8		20	360	0.77	1228.37	1228	61
North Hall		720	10		-	-				19	1500	0.8		20	380	0.53	1296.61	1297	65
West Hall		377	10		-	-				15	1500	0.8		20	300	0.8	1023.64	1024	51
South Hall		168	10		6.833	24.25				8	1500	0.8		20	160	0.95	545.94	546	29
Totals															6036		20594	163685	7834

Third Floor

		Room Area	Height	Perimeter	Length	Width	Room Cavity Ratio	Coefficient of Utilization	Luminaires /Fixture	Number of Fixtures	Lumens	Light Loss Factor	Footcandles	Watts	W/Room	W/Area	Lights	BTUH/Room	CFM
Room			**H**	**P**	**L**	**W**	**RCR**	**CU**	**n**	**N**	**F**	**LLF**	**E**	**W**			**BTUH**		
Studio 1		1311	9.5	-	31.083	41.833	2.6	0.91	1	13	5565	0.8	40	50.9	661.7	0.5	2257.81	39072	1872
Studio 2		1136	9.5	-	32.583	34.833	2.8	0.91	1	11	5565	0.8	40	50.9	559.9	0.49	1910.46	38724	1855
Studio 3		1581	9.5	166	-	-	2.5	0.91	1	16	5565	0.8	40	50.9	814.4	0.52	2778.85	39593	1897
Tech Suite 1		187	9.5	-	13.083	13.833	6.8	0.57	1	2	5565	0.8	30	50.9	101.8	0.54	347.36	3467	168
Tech Suite 2		186	9.5	-	13.083	13.833	6.9	0.57	1	2	5565	0.8	30	50.9	101.8	0.55	347.36	3467	168
Classroom		547	9.5	92.83	-	-	4	0.71	1	7	5565	0.8	40	50.9	356.3	0.65	1215.75	11164	537
Presentation Room 2		482	9.5	-	17.75	27.083	4.4	0.71	1	5	5565	0.8	35	50.9	254.5	0.53	868.39	11238	540
Presentation Room 1		494	9.5	-	15.5	32.167	4.6	0.71	1	5	5565	0.8	35	50.9	254.5	0.52	868.39	14988	720
Storage Room		83	9.5	-	8.25	9.583	10.2	0.4	1	1	5565	0.8	20	50.9	50.9	0.61	173.68	174	11
Men's Bathroom		214	9.5	-	14.417	14.833	6.5	0.57	1	2	5565	0.8	18	50.9	101.8	0.48	347.36	347	19
Women's Bathroom		214	9.5	-	14.417	14.833	6.5	0.57	1	2	5565	0.8	18	50.9	101.8	0.48	347.36	347	19
Study Stairs		687	9.5	130.5	-	-	4.5	0.71	1	6	5565	0.8	28	50.9	305.4	0.44	1042.07	6042	292
Open Area		645	9.5	125.83	-	-	4.6	0.71	1	6	5565	0.8	28	50.9	305.4	0.47	1042.07	4792	232
Egress North		347	9.5	-	26	13.333	5.4	0.63	1	3	5565	0.8	25	50.9	152.7	0.44	521.03	521	27
Egress South		414	9.5	-	26.5	15.417	4.8	0.71	1	3	5565	0.8	25	50.9	152.7	0.37	521.03	521	27
East Hall		519	9.5	127.167	-	-				20	1500			20	400	0.77	1364.86	1365	68
North Hall		825	9.5	194.417	-	-				24	1500			20	480	0.58	1637.83	1638	81
West Hall		210	9.5	79.417	-	-				8	1500			20	160	0.76	545.94	546	29
South Hall		421	9.5	96.25	-	-				10	1500			20	200	0.48	682.43	682	35
Totals															**5516**		**18820**	**178689**	**8552**

Second Floor

		Room Area	Height	Perimeter	Length	Width	Room Cavity Ratio	Coefficient of Utilization	Luminaires /Fixture	Number of Fixtures	Lumens	Light Loss Factor	Footcandles	Watts	W/Room	W/Area	Lights	BTUH/Room	CFM
Room			**H**	**P**	**L**	**W**	**RCR**	**CU**	**n**	**N**	**F**	**LLF**	**E**	**W**			**BTUH**		
Office 1		172	6.5	-	16.917	14.333	5.9	0.63	1	2	5565	0.8	30	50.9	101.8	0.59	347.36	1620	80
Office 2		198	6.5	-	13.583	14.333	4.6	0.71	1	2	5565	0.8	30	50.9	101.8	0.51	347.36	1620	80
Office 3		200	6.5	-	13.583	14.583	4.6	0.71	1	2	5565	0.8	30	50.9	101.8	0.51	347.36	1620	80
Office 4		200	6.5	-	13.583	14.583	4.6	0.71	1	2	5565	0.8	30	50.9	101.8	0.51	347.36	1620	80
Office 5		196	6.5	-	13.583	14.333	4.6	0.71	1	2	5565	0.8	30	50.9	101.8	0.52	347.36	1620	80
Office 6		155	6.5	-	13	11.917	5.2	0.63	1	2	5565	0.8	30	50.9	101.8	0.66	347.36	1620	80
Office 7		158	6.5	-	13.25	11.917	5.2	0.63	1	2	5565	0.8	30	50.9	101.8	0.64	347.36	1620	80
Office 8		158	6.5	-	13.25	11.917	5.2	0.63	1	2	5565	0.8	30	50.9	101.8	0.64	347.36	1620	80
Office 9		170	6.5	-	13.667	12.417	5	0.71	1	2	5565	0.8	30	50.9	101.8	0.6	347.36	1620	80
Office 10		166	6.5	-	13.667	12.083	5	0.63	1	2	5565	0.8	30	50.9	101.8	0.61	347.36	1620	80
Office 11		185	6.5	-	15.25	12.083	4.8	0.71	1	2	5565	0.8	30	50.9	101.8	0.55	347.36	1620	80
Office 12		186	6.5	-	14.917	12.417	4.8	0.71	1	2	5565	0.8	30	50.9	101.8	0.55	347.36	1620	80
Office 13		181	6.5	-	14.197	12.083	4.7	0.71	1	2	5565	0.8	30	50.9	101.8	0.56	347.36	1620	80
Administrative Area		380	6.5	80	-	-	3.4	0.8	1	3	5565	0.8	30	50.9	152.7	0.4	521.03	1794	88
Faculty Lounge		765	6.5	118	-	-	2.5	0.91	1	5	5565	0.8	20	50.9	254.5	0.33	868.39	14308	687
Copy Room		246	6.5	65	-	-	4.3	0.71	1	2	5565	0.8	25	50.9	101.8	0.41	347.36	7503	361
Computer Lab		1157	6.5	-	30.167	38.667	1.9	1.04	1	10	5565	0.8	42	50.9	509	0.44	1736.78	68943	3301
Conference Room 1		442	6.5	-	27.083	16.333	3.2	0.8	1	5	5565	0.8	40	50.9	254.5	0.58	868.39	7488	361
Conference Room 2		295	6.5	-	24	12.25	4	0.8	1	3	5565	0.8	40	50.9	152.7	0.52	521.03	5891	284
Conference Room 3		379	6.5	-	26.5	13.833	3.5	0.8	1	6	5565	0.8	40	50.9	305.4	0.81	1042.07	7662	369
Storage Room		83	6.5	-	8.25	9.583	7	0.57	1	1	5565	0.8	20	50.9	50.9	0.61	173.68	174	11
Large Storage Room		190	6.5	-	15.25	12.417	4.7	0.71	1	1	5565	0.8	20	50.9	50.9	0.27	173.68	174	11
Men's Bathroom		214	6.5	-	14.417	14.833	4.4	0.71	1	2	5565	0.8	18	50.9	101.8	0.48	347.36	347	19
Women's Bathroom		214	6.5	-	14.417	14.833	4.4	0.71	1	2	5565	0.8	18	50.9	101.8	0.48	347.36	347	19
Open Area		623	6.5	126.833	-	-	3.3	0.8	1	7	5565	0.8	28	50.9	356.3	0.57	1215.75	4966	240
Egress North		347	6.5	-	26	13.333	3.7	0.8	1	2	5565	0.8	25	50.9	101.8	0.29	347.36	347	19
Egress South		414	6.5	-	26.5	15.417	3.3	0.8	1	3	5565	0.8	25	50.9	152.7	0.37	521.03	521	27
East Hall		676	6.5	185.33	-	-				22	1500			20	440	0.65	1501.34	1501	74
Center Hall		493	6.5	146.582	-	-				17	1500			20	340	0.69	1160.13	1160	58
West Hall		769	6.5	210.084	-	-				36	1500			20	720	0.94	2456.74	2457	120
South Hall		1038	6.5	-	6.833	24				6	1500			20	120	0.12	409.46	409	22
Totals															**5590**		**19075**	**147057**	**7039**

First Floor

		Room Area	Height	Perimeter	Length	Width	Room Cavity Ratio	Coefficient of Utilization	Luminaires /Fixture	Number of Fixtures	Lumens	Light Loss Factor	Footcandles	Watts	W/Room	W/Area	Lights	BTUH/Room	CFM
Room			**H**	**P**	**L**	**W**	**RCR**	**CU**	**n**	**N**	**F**	**LLF**	**E**	**W**			**BTUH**		
TA Offices Area		1608	6.5	243	-	-	2.5	0.91	1	16	5565	0.8	40	50.9	814.4	0.51	2778.85	30370	1456
Student Lounge		3177	6.5	233.167	-	-	1.2	1.04	1	19	5565	0.8	28	50.9	967.1	0.3	3299.88	9550	459
Mechanical Room		543	6.5	-	15.917	34.417	3	0.8	1	3	5565	0.8	20	50.9	152.7	0.28	521.03	1021	51
Men's Bathroom		214	6.5	-	14.417	14.833	4.4	0.71	1	2	5565	0.8	18	50.9	101.8	0.48	347.36	347	19
Women's Bathroom		214	6.5	-	14.417	14.833	4.4	0.71	1	2	5565	0.8	18	50.9	101.8	0.48	347.36	347	19
Egress South		253	6.5	-	26.5	15.417	5.4	0.63	1	2	5565	0.8	25	50.9	101.8	0.4	347.36	347	19
West Hall		544	6.5	114.249	-	-	3.4	0.8	1	4	5565	0.8	25	50.9	203.6	0.37	694.71	695	36
Totals															**2443**		**8337**	**42678**	**2044**

Appendix C - Building Enclosure Classification

Areas			
A_g	8622.5		SF
A_o	6633.48		SF
A_{gi}	1610.5		SF
A_{oi}	429.52		SF
For "Open" Classification:			
$A_o > 0.8A_g$			
6633	>	6898	**FALSE**
Building does not satisfy "Open" requirements.			
For "Partially Enclosed" Classification:			
1. $A_o > 1.1A_{oi}$			
6633	>	472	**TRUE**
2. $A_o > 4$ or $0.01A_g$			
6633	>	4	**TRUE**
6633	>	86	**TRUE**
3. $A_{oi}/A_{gi} < 0.2$			
0.27	<	0.2	**FALSE**
Building does not satisfy "Partially Enclosed" requirements.			
For "Enclosed" Classification:			
Building does not satisfy either Open or Partially Enclosed definitions.			

Appendix D - Curved Member Sizing

Member Identification						**Comments:**
Level	4					
Bay	Curved					
Start/End	B to F					
1. Calculate Tributary Area						
Length	23.75	ft				
Tributary Area	483.53	ft				Calculated in Revit
2. Calculate Design Loads						
Live Load (L)	100	psf	=	2036	plf	Section 3.2.1
Dead Load (D)	58.3	psf	=	1198	plf	Section 3.2.2
1.4D	81.62	psf		1677	plf	
1.2D+1.6L	229.96	psf		4695	plf	
3. Calculate Required Moment and Section Modulus						
Moment (M_u)	331.05	ft-kip				Equation 16
Section Modulus (Z_x)	88.28	in^3				Equation 17
4. Select Member from AISC Table 3-2 that Meets Required M_u and Z_x						
Member	W21x55					
Section Modulus (Z)	126	in^3				
Moment of Inertia (I)	140	in^4				
5. Revise Calculated Values to Include Self-Weight of Selected Member						
Revised Load	4761.18	plf				
Revised M_u	335.70	ft-kip				
Revised Z_x	89.52	in^3	<	Z	OK	
6. Check Deflection Limit						
Live Load Deflection Limit (Δ_{allow})	0.79	in				Equation 18
Live Load Deflection (Δ_{LL})	0.44	in	<	Δ_{allow}	OK	L/360 by 2015 IBC Table 1604.3

Appendix E - Peak Loads

First Floor

	Orientation	Wall			Glass			Room	Roof	Peak	Peak	Total	Wall		Glass				Roof		Heat
Room		**Area**	**Grp**	**U**	**Area**	**U**	**SC**	**Area**	**U**	**Mnth**	**Hour**	**S&T**	**CLTD**	**BTUH**	**SHGF**	**CLF**	**CLTD**	**BTUH**	**CLTD**	**BTUH**	**Loss**
TA Offices	SE	113.22	D	0.054	59.22	0.42	0.4	4690		9	11	3692	22	133	226	0.63	7.5	3559	32	0	2172
	NE	454.5	D	0.054	135	0.42	0.4			9	11	2566	13	309	87	0.39	7.5	2257	32	0	5701
	NW	639	D	0.064	0		0.4			9	11	102	3	102	87	0.16	7.5	0	32	0	736
												6360									8610
Mechanical Room	W	141.75	D	0.064	0		0.4	543		9	20	340	38	340	203	0.34	8.5	0	31	0	163
	S	309.78	D	0.064	0		0.4			9	20	783	40	783	200	0.22	8.5	0	31	0	357
												1123									520
Bathroom	NW	129.78	D	0.064	0		0.4	213		6	20	270	33	270	172	0.33	8.5	0	41	0	150
South Stair	E	138.78	D	0.054	116.47	0.42	0.4	414		9	13	4319	28	208	203	0.37	12.5	4111	55	0	3953
	S	238.5	D	0.054	110.66	0.42	0.4			9	13	6628	23	292	200	0.65	12.5	6336	55	0	4162
												10947									8115
Open Area	SE	367.47	D	0.054	367.47	0.42	0.4	3177		9	11	22516	22	430	226	0.63	7.5	22086	32	0	12204
	E	126.72	D	0.054	126.72	0.42	0.4			9	11	5679	20	135	203	0.5	7.5	5544	32	0	483
												28195									12687
West Hall	W	382.5	D	0.064	0		0.4	253		6	21	1040	43	1040	216	0.27	6.5	0	31	0	441

Second Floor

	Orientation	Wall			Glass			Room	Roof	Peak	Peak	Total	Wall		Glass				Roof		Heat
Room		**Area**	**Grp**	**U**	**Area**	**U**	**SC**	**Area**	**U**	**Mnth**	**Hour**	**S&T**	**CLTD**	**BTUH**	**SHGF**	**CLF**	**CLTD**	**BTUH**	**CLTD**	**BTUH**	**Loss**
Office 1	SE	152.28	D	0.054	152.28	0.42	0.4	172		9	11	9331	22	178	226	0.63	7.5	9152	32	0	5057
Office 2	SE	122.22	D	0.054	59.22	0.42	0.4	198		9	11	3702	22	143	226	0.63	7.5	3559	32	0	2207
	NE	128.97	D	0.054	27	0.42	0.4			9	11	539	13	88	87	0.39	7.5	451	32	0	1285
												4242									3492
Office 3	NE	131.22	D	0.054	54	0.42	0.4	200		6	9	2034	12	82	172	0.51	2.5	1951	17	0	2088
Office 4	NE	131.22	D	0.054	27	0.42	0.4	200		6	9	1058	12	82	172	0.51	2.5	979	17	0	1294
Office 5	NE	128.97	D	0.054	54	0.42	0.4	196		6	9	2032	12	81	172	0.51	2.5	1951	17	0	2079
Office 6	NW	58.5	D	0.054	6	0.42	0.4	155		6	18	354	24	75	172	0.6	12.5	279	65	0	399
	NW	58.5		0.071	0					6	18	100	24	100	172	0.6	12.5	0	65	0	75
												454									474
Office 7	NW	26.5	D	0.054	3	0.42	0.4	158		6	18	173	24	34	172	0.6	12.5	140	65	0	189
	NW	92.75		0.064						6	18	142	24	142	172	0.6	12.5	0	65	0	107
												316									296
Office 8	NW	119.25	D	0.054	6	0.42	0.4	158		6	18	432	24	153	172	0.6	12.5	379	65	0	631
	NW	125.875		0.064						6	18	193	24	193	172	0.6	12.5	0	65	0	145
												625									776
Conference Room	NW	146.97	D	0.064	0			442		6	21	315	34	315	172	0.26	6.5	0	31	0	169
Admin Area	NW	148.5	D	0.064	0			380		6	21	318	34	318	172	0.26	6.5	0	31	0	171
Copy Room	W	222.03	D	0.064	0			246		6	21	604	43	604	216	0.27	6.5	0	31	0	256
Faculty Lounge	W	290.97	D	0.064	0			765		6	21	791	43	791	216	0.27	6.5	0	31	0	335
Computer Lab	W	272.25	D	0.064	0			1157		9	21	671	39	671	203	0.27	6.5	0	21	0	314
	S	348.03	D	0.064	0					9	21	835	38	835	200	0.18	6.5	0	21	0	401
												1506									715
Conference Room	S	110.25	D	0.054	54	0.42	0.4	295		9	14	3273	27	159	200	0.65	13.5	3114	63	0	2008

Conference Room	E	124.47	D	0.054	124.47	0.42	0.4	379		6	10	6490	19	125	216	0.57	4.5	6365	30	0	4134
North Stair	NE	234	D	0.054	110.66	0.42	0.4	347		6	17	2703	26	325	172	0.23	13.5	2379	73	0	4145
	NW	119.97	D	0.054	110.66	0.42	0.4			6	17	5247	20	127	172	0.59	13.5	5120	73	0	3711
												7950									7856
South Stair	E	138.78	D	0.054	116.47	0.42	0.4	414		9	13	4319	28	208	203	0.37	12.5	4111	55	0	3953
	S	238.5	D	0.054	110.66	0.42	0.4			9	13	6628	23	292	200	0.65	12.5	6336	55	0	4162
												10946									8116
South Hall	S	61.47	D	0.054	27	0.42	0.4	166		9	14	1646	27	89	200	0.65	13.5	1557	63	0	1028
Open Area	SE	213.03	D	0.054	213.03	0.42	0.4	138		9	11	13053	22	249	226	0.63	7.5	12804	32	0	7075

Third Floor

	Orientation	Wall			Glass			Room	Roof	Peak	Peak	Total	Wall		Glass				Roof		Heat
Room		**Area**	**Grp**	**U**	**Area**	**U**	**SC**	**Area**	**U**	**Mnth**	**Hour**	**S&T**	**CLTD**	**BTUH**	**SHGF**	**CLF**	**CLTD**	**BTUH**	**CLTD**	**BTUH**	**Loss**
Studio 1	SE	372.96	D	0.054	288.96	0.42	0.4	1311		9	11	17804	22	437	226	0.63	7.5	17367	32	0	9512
	NE	501.96	D	0.054	144	0.42	0.4			9	11	2750	13	342	87	0.39	7.5	2408	32	0	5945
												20553									15457
Studio 2	NW	390.96	D	0.054	144	0.42	0.4	1136		6	18	7200	24	500	172	0.6	12.5	6700	65	0	5522
Presentation Roor	NW	213	D	0.054	72	0.42	0.4	482		6	18	3623	24	272	172	0.6	12.5	3350	65	0	2828
Classroom	NW	267.96	D	0.054	36	0.42	0.4	547		6	18	2018	24	343	172	0.6	12.5	1675	65	0	2029
Studio 3	W	482.04	D	0.064	0	0.42	0.4	1652		9	14	262	9	262	203	0.32	13.5	0	63	0	555
	S	609.96	D	0.054	180	0.42	0.4			9	14	11261	27	880	200	0.65	13.5	10381	63	0	7364
												11523									7920
Tech Suite 2	E	165.96	D	0.054	165.96	0.42	0.4	186		6	10	8654	19	167	216	0.57	4.5	8487	30	0	5279
North Stair	NE	312	D	0	174.66	0.42	0.4	347		6	17	4187	26	433	172	0.23	13.5	3754	73	0	6324
	NW	159.96	D	0	138.66	0.42	0.4			6	17	6585	20	170	172	0.59	13.5	6415	73	0	4686
												10772									11010
Study Stairs	WNW	555.96	D	0.054	0			913		6	21	1256	42	1256	205	0.27	6.5	0	31	0	2119
																					0
South Hall	S	87.96	D	0.054	36	0.42	0.4	421		9	14	2203	27	127	200	0.65	13.5	2076	63	0	1343
Open Area	SE	284.04	D	0.054	284.04	0.42	0.4	872		9	11	17404	22	332	226	0.63	7.5	17071	32	0	9035
East Hall	NE	201.96	D	0.054	108	0.42	0.4	519		6	9	4029	12	126	172	0.51	2.5	3903	17	0	3794
North Hall								825													
West Hall								210													
South Stair	E	185.04	D	0.054	145.94	0.42	0.4	414		9	13	5428	28	277	203	0.37	12.5	5151	55	0	4792
	S	318	D	0.054	138.66	0.42	0.4			9	13	8328	23	389	200	0.65	12.5	7939	55	0	5288
												13756									10080

Fourth Floor

	Orientation	Wall			Glass			Room	Roof	Peak	Peak	Total	Wall		Glass				Roof		Heat
Room		**Area**	**Grp**	**U**	**Area**	**U**	**SC**	**Area**	**U**	**Mnth**	**Hour**	**S&T**	**CLTD**	**BTUH**	**SHGF**	**CLF**	**CLTD**	**BTUH**	**CLTD**	**BTUH**	**Loss**
Classroom 1	SE	387.5	D	0.054	299	0.42	0.4	625	0.037	9	11	19152	22	454	226	0.63	7.5	17970	32	728	11886
	NE	247.89	D	0.054	75	0.42	0.4			9	11	1423	13	169	87	0.39	7.5	1254	32	0	3150
												20575									15035
Classroom 2	NE	269.75	D	0.054	75	0.42	0.4	669	0.037	6	15	4155	25	360	172	0.28	14.5	1902	77	3053	4966

Lecture Hall 1	NW	407.25	D	0.054	150	0.42	0.4	1138	0.037	6	17	10424	20	432	172	0.59	13.5	6939	73	3053	8909
Classroom 3	NW	312.5	D	0.054	112.5	0.42	0.4	678	0.037	6	17	7355	20	332	172	0.59	13.5	5204	73	1819	6254
Lecture Hall 2	W	561.5	D	0.054	225	0.42	0.4	1587	0.037	8	17	18430	25	749	216	0.64	13.5	13717	68	3964	12865
	S	479.13	D	0.054	150	0.42	0.4			8	17	5516	32	822	149	0.43	13.5	4695	68	0	6236
												23946									19101
Conference Room	S	157.25	D	0.054	75	0.42	0.4	306	0.037	9	14	5260	27	227	200	0.65	13.5	4325	63	708	3597
Conference Room	E	172.88	D	0.054	172.875	0.42	0.4	379	0.037	6	10	9428	19	174	216	0.57	4.5	8840	30	414	6723
North Stairs	NE	325	D	0.054	137.5	0.42	0.4	347	0.037	6	15	4902	25	433	172	0.28	14.5	3486	77	982	6180
	NW	166.625	D	0.054	100	0.42	0.4			6	17	4803	20	177	172	0.59	13.5	4626	73	0	3575
												9705									9755
South Stair	E	192.75	D	0.054	105.25	0.42	0.4	414	0.037	9	14	4598	30	310	203	0.32	13.5	3332	63	957	4901
	S	331.25	D	0.054	100	0.42	0.4			9	14	6245	27	478	200	0.65	13.5	5767	63	0	4202
												10843									9103
Entrance	NW	712.5	D	0.054	650	0.42	0.4	1225	0.037	6	17	34113	20	756	172	0.59	13.5	30070	73	3286	24998
South Hall	S	85.375		0.054	37.5	0.42	0.4	168	0.037	9	14	2677	27	125	200	0.65	13.5	2163	63	389	1863
Open Area	SE	295.75		0.054	295.75	0.42	0.4	877	0.037	9	11	19152	22	354	226	0.63	7.5	17775	32	1022	12093
East Hall	NE	210.375		0.054	75	0.42	0.4	465	0.037	6	15	3504	25	286	172	0.28	14.5	1902	77	1316	4211

Appendix F - Internal Load Calculations

Fourth Floor				
Room	**Total Occupants**	**People Load**	**Equipment Load**	**Latent (People)**
Tech Suite 1	6	1500	1619.75	1200
Tech Suite 2	6	1500	1619.75	1200
Tech Suite 3	6	1500	1619.75	1200
Classroom 1	35	8750	2448.38	7000
Classroom 2	40	10000	2448.38	8000
Classroom 3	40	10000	2448.38	8000
Conference Room 1	14	3500	1619.75	2800
Conference Room 2	14	3500	1619.75	2800
Lecture Hall 1	100	25000	2448.38	20000
Lecture Hall 2	200	50000	2448.38	40000
Storage Room	0	0	0	0
Men's Bathroom	0	0	0	0
Women's Bathroom	0	0	0	0
Entrance	15	3750	0	3000
Open Area	15	3750	0	3000
Egress North	0	0	0	0
Egress South	0	0	0	0
East Hall	0	0	0	0
North Hall	0	0	0	0
West Hall	0	0	0	0
South Hall	0	0	0	0
Totals		**122750**	**20340.65**	**98200**

Third Floor				
Room	**Total Occupants**	**People Load**	**Equipment Load**	**Latent (People)**
Studio 1	25	6250	30563.83	5000
Studio 2	25	6250	30563.83	5000
Studio 3	25	6250	30563.83	5000
Tech Suite 1	6	1500	1619.75	1200
Tech Suite 2	6	1500	1619.75	1200
Classroom	30	7500	2448.38	6000
Presentation Room 2	35	8750	1619.75	7000
Presentation Room 1	50	12500	1619.75	10000
Storage Room	0	0	0	0
Men's Bathroom	0	0	0	0
Women's Bathroom	0	0	0	0
Study Stairs	20	5000	0	4000
Open Area	15	3750	0	3000
Egress North	0	0	0	0
Egress South	0	0	0	0
East Hall				0
North Hall				0
West Hall				0
South Hall				0
Totals		**59250**	**100618.87**	**47400**

Second Floor				
Room	**Total Occupants**	**People Load**	**Equipment Load**	**Latent (People)**
Office 1	1	250	1023	200
Office 2	1	250	1023	200
Office 3	1	250	1023	200
Office 4	1	250	1023	200
Office 5	1	250	1023	200
Office 6	1	250	1023	200
Office 7	1	250	1023	200
Office 8	1	250	1023	200
Office 9	1	250	1023	200
Office 10	1	250	1023	200
Office 11	1	250	1023	200
Office 12	1	250	1023	200
Office 13	1	250	1023	200
Administrative Area	1	250	1023	200
Faculty Lounge	20	5000	8439.75	4000
Copy Room	1	250	6905.25	200
Computer Lab	50	12500	54706.63	10000
Conference Room 1	20	5000	1619.75	4000
Conference Room 2	15	3750	1619.75	3000
Conference Room 3	20	5000	1619.75	4000
Storage Room	0	0	0	0
Large Storage Room	0	0	0	0
Men's Bathroom	0	0	0	0
Women's Bathroom	0	0	0	0
Open Area	15	3750	0	3000
Egress North	0	0	0	0
Egress South	0	0	0	0
East Hall				0
Center Hall				0
West Hall				0
South Hall				0
Totals		**38750**	**89232.88**	**31000**

First Floor				
Room	**Total Occupants**	**People Load**	**Equipment Load**	**Latent (People)**
TA Offices Area	20	5000	22591.25	4000
Student Lounge	25	6250	0	5000
Mechanical Room	2	500		400
Men's Bathroom	0	0	0	0
Women's Bathroom	0	0	0	0
Egress South	0	0	0	0
West Hall				
Totals		**11750**	**22591.25**	**9400**

Appendix G - Stud Wall R-Value

Figure 2 - Effective Insulation/Framing Layer R-values for Wall Insulation Between Steel Framing

Nominal depth of cavity	Actual depth of cavity	Rated R-value of air space or insulation	Effective framing/cavity R-value	
			At 406 mm (16 in.) on center	At 609 mm (24 in.) on center
Empty Cavity, No Insulation				
102 mm (4 in.)	89 mm (3.5 in.)	0.91	0.79	0.91
Insulated Cavity				
102 mm	89 mm	11	5.5	6.6
102 mm	89 mm	13	6	7.2
102 mm	89 mm	15	6.4	7.8
152 mm (6 in.)	152 mm	19	7.1	8.6
152 mm	152 mm	21	7.4	9
203 mm (8 in.)	203 mm	25	7.8	9.6

From ASHRAE 90.1, Table A9.2B

Appendix H - Underground Wall U-Value

Table 7.10A Heat Loss for Below-Grade Walls with Insulation on Inside Surface — (For walls extending more than 3 ft below grade) Average Btu/(hr·ft²·F)

Distance Wall Extends Below-Grade,* ft	Insulation Over Full Surface			Wall Insulated to a Depth of Two Feet Below Grade		
	R-4	R-8	R-13	R-4	R-8	R-13
4	0.110	0.075	0.057	0.136	0.102	0.090
5	0.102	0.071	0.054	0.128	0.100	0.091
6	0.095	0.067	0.052	0.120	0.097	0.089
7	0.089	0.064	0.050	0.112	0.093	0.086

* For a depth below-grade of 3 feet or less, treat as a slab on grade.

Appendix I - Zoning Plans

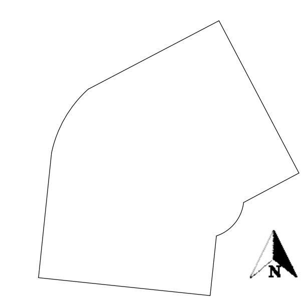
Room Schedule - First Floor	
Number	Type
2	Lobby
1	TA Office
6	Mechanical Room
5	Bathroom
4	Bathroom
3	Storage Room
7	South Egress Stairs

1 Level 1
1/16" = 1'-0"

A18 WPI

Worcester Polytechnic Institute
100 Institute Rd.
Worcester, MA 01609

Design of AREN Building for WPI Campus



Design Documents

No.	Description	Date

First Floor Plan

Scale	1/16" = 1'-0"
Date	03/03/2016
Drawn by	KEM
Checked by	MCH, CLT, MCT

A101

Room Schedule - Second Floor	
Number	Type
8	North Egress Stairs
9	Office
10	Office
11	Office
12	Office
13	Office
14	Office
15	Office
16	Office
17	Office
18	Office
19	Office
20	Storage Room
21	Office
22	Office
23	Open Area
24	Conference Room
25	Admin Area
26	Storage Room
27	Bathroom
28	Bathroom
29	Conference Room
30	Copy Room
31	Faculty Lounge
32	Computer Lab
33	Conference Room

1 Level 2
1/16" = 1'-0"

A19 WPI

Worcester Polytechnic Institute
100 Institute Rd.
Worcester, MA 01609

Design of AREN Building for WPI Campus

Design Documents

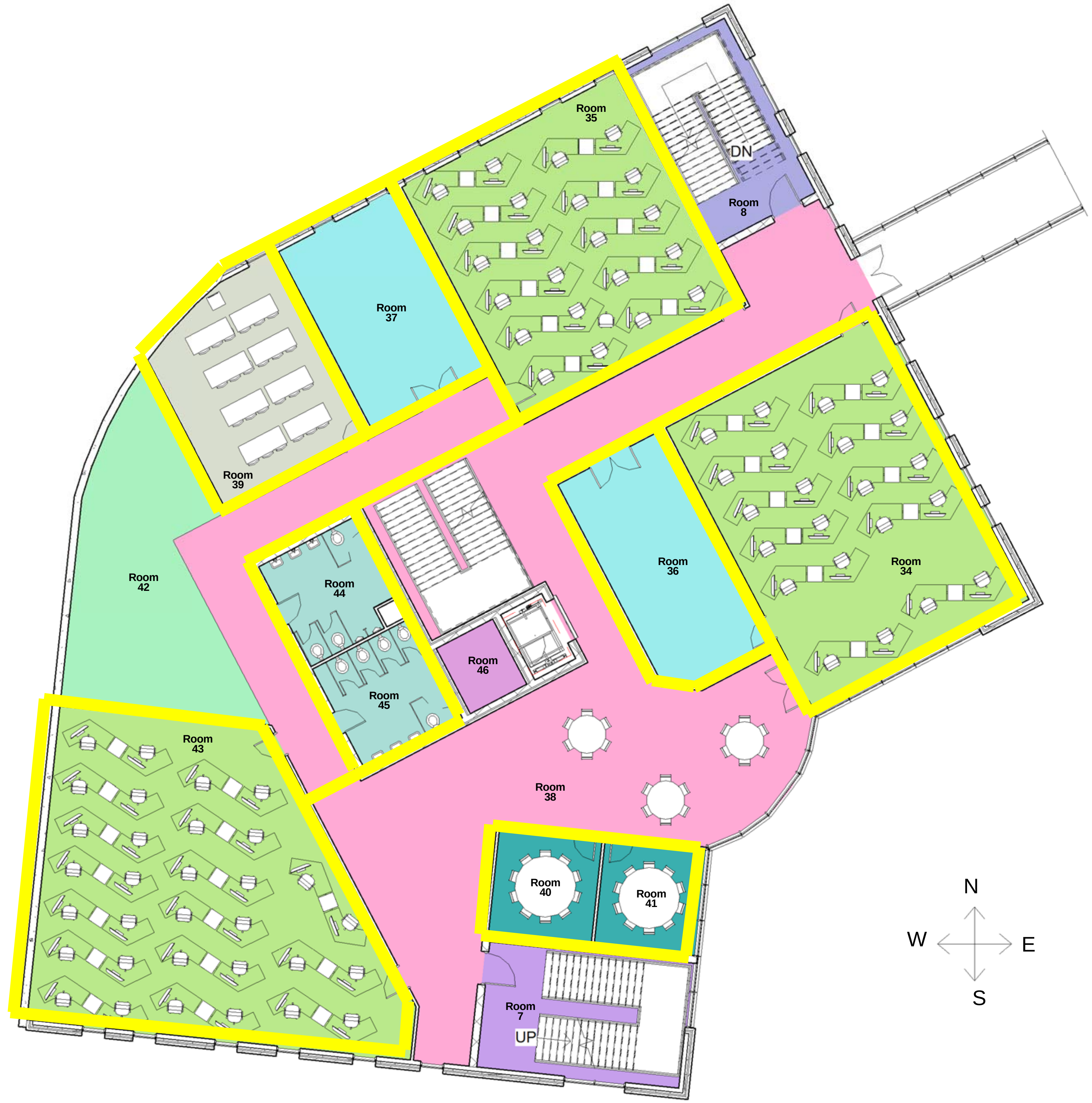
No.	Description	Date

Second Floor Plan

Scale	1/16" = 1'-0"
Date	03/03/2016
Drawn by	KEM
Checked by	MCH, CLT, MCT

A102

Room Schedule - Third Floor	
Number	Type
34	Studio
35	Studio
36	Presentation Room
37	Presentation Room
38	Open Area
39	Classroom
40	Tech Suite
41	Tech Suite
42	Study Stairs
43	Studio
44	Bathroom
45	Bathroom
46	Mechanical Shaft

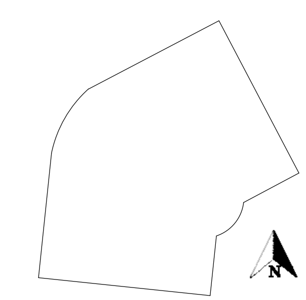


1 Level 3
1/16" = 1'-0"

A20

Worcester Polytechnic Institute
100 Institute Rd.
Worcester, MA 01609

Design of AREN Building for WPI Campus



Design Documents

No.	Description	Date

Third Floor Plan

Scale	1/16" = 1'-0"
Date	03/03/2016
Drawn by	KEM
Checked by	MCH, CLT, MCT

A103

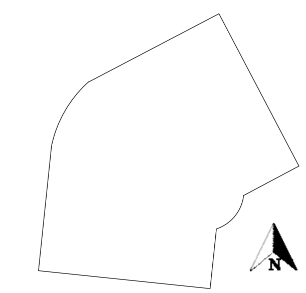
Room Schedule - Fourth Floor	
Number	Type
47	Lecture Hall
48	Classroom
49	Classroom
50	Tech Suite
51	Tech Suite
52	Tech Suite
53	Classroom
54	Open Area
55	Conference Room
56	Lecture Hall
57	Conference Room

1 Level 4
1/16" = 1'-0"

A21

Worcester Polytechnic Institute
100 Institute Rd.
Worcester, MA 01609

Design of AREN Building for WPI Campus



Design Documents

No.	Description	Date

Fourth Floor Plan

Scale	1/16" = 1'-0"
Date	03/03/2016
Drawn by	KEM
Checked by	MCH, CLT, MCT

A104

Appendix J - Ventilation and Latent Requirements

ASHRAE 62.1-2010

Table 6-1

Reference Values			
Room	CFM/person	CFM/ft^2	#/1000ft^2
Classroom	10	0.12	35
Lecture Classroom	7.5	0.06	65
Lecture Hall	7.5	0.06	150
Computer Lab	10	0.12	25
Break Room	5	0.06	25
Conference Room	5	0.06	50
Corridor	-	0.06	-
Open Space	5	0.06	30-50

First Floor

Room	Area	CFM/ft^2	Occupants	CFM/person	Ventilation CFM	Latent Load BTUH	Latent CFM	Min. CFM Required
TA Offices	1608	0.06	20	5	196.48	4000	732.9	735
Student Lounge	3437	0.06	25	5	331.22	5000	916.1	920
Mechanical Room	543	0.06	0	-	32.58	0	0.0	35
Totals:					**560.28**	**9000**		**1690**

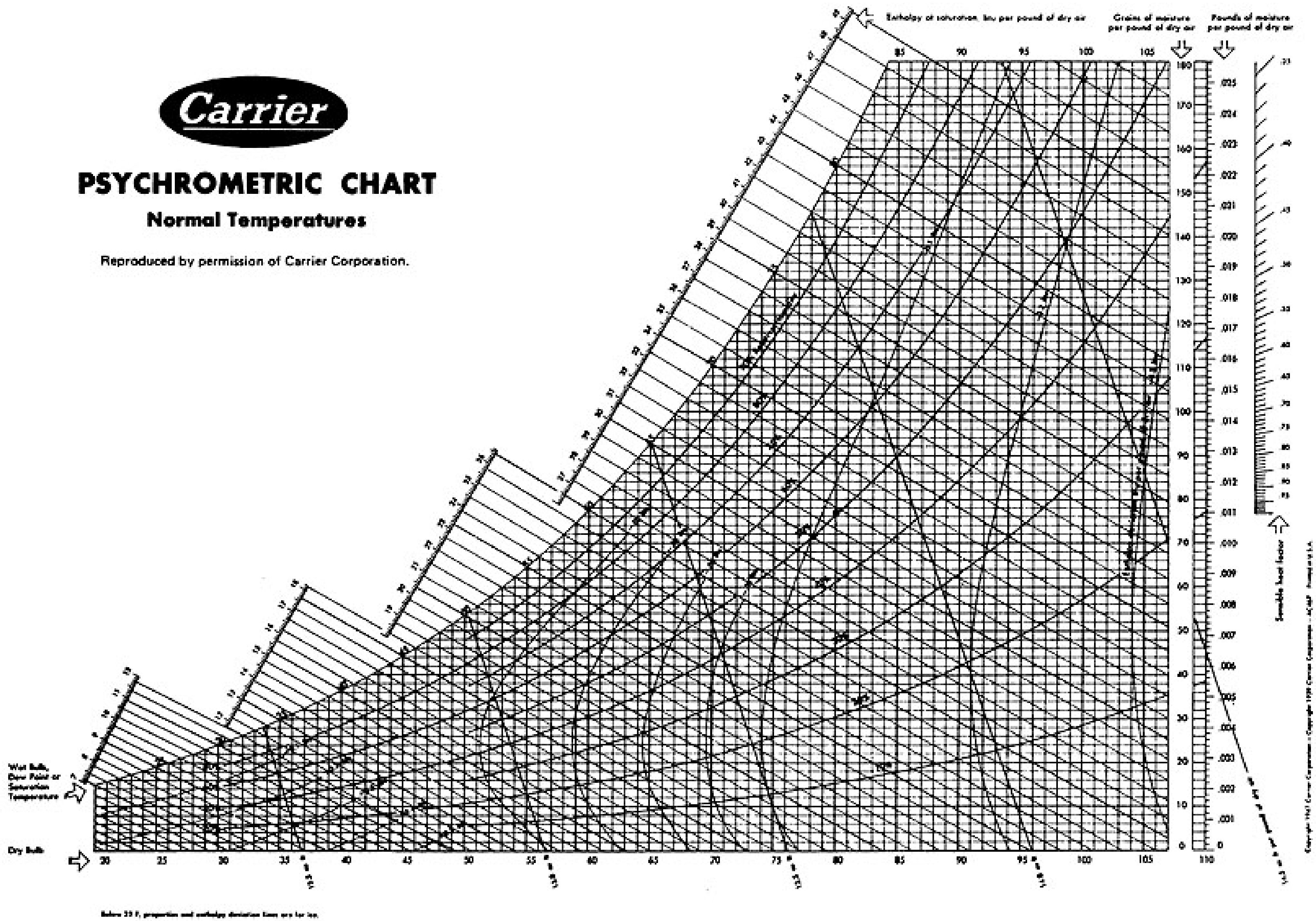
Second Floor

Room	Area	CFM/ft^2	Occupants	CFM/person	Ventilation CFM	Latent Load BTUH	Latent CFM	Min. CFM Required
Office 1	172	0.06	1	5	15.32	200	36.6	40
Office 2	198	0.06	1	5	16.88	200	36.6	40
Office 3	200	0.06	1	5	17	200	36.6	40
Office 4	200	0.06	1	5	17	200	36.6	40
Office 5	196	0.06	1	5	16.76	200	36.6	40
Office 6	155	0.06	1	5	14.3	200	36.6	40
Office 7	158	0.06	1	5	14.48	200	36.6	40
Office 8	158	0.06	1	5	14.48	200	36.6	40
Office 9	170	0.06	1	5	15.2	200	36.6	40
Office 10	166	0.06	1	5	14.96	200	36.6	40
Office 11	185	0.06	1	5	16.1	200	36.6	40
Office 12	186	0.06	1	5	16.16	200	36.6	40
Office 13	181	0.06	1	5	15.86	200	36.6	40
Admin Area	380	0.06	1	5	27.8	200	36.6	40
Faculty Lounge	765	0.06	20	5	145.9	4000	732.9	735
Copy Room	246	0.06	0	5	14.76	0	0.0	15
Computer Lab	1157	0.12	50	10	638.84	10000	1832.2	1850
Conference Room 1	442	0.06	15	5	101.52	3000	549.7	550
Conference Room 2	295	0.06	10	5	67.7	2000	366.4	370
Conference Room 3	379	0.06	15	5	97.74	3000	549.7	550
Open Area	3487	0.06	15	5	284.22	3000	549.7	550
Totals:					**1582.98**	**27800**	**5093.5**	**5180**

Third Floor						
Room	**Area**	**CFM/ft^2**	**Occupants**	**CFM/person**	**Ventilation CFM**	**Latent Load BTUH**
Studio 1	1311	0.06	25	5	204	5000
Studio 2	1136	0.06	25	5	193	5000
Studio 3	1581	0.06	25	5	220	5000
Tech Suite 1	187	0.06	6	5	41	1200
Tech Suite 2	186	0.06	6	5	41	1200
Classroom	547	0.12	30	10	366	6000
Presentation Room 1	494	0.06	50	5	280	10000
Presentation Room 2	482	0.06	35	5	204	7000
Study Stairs	1431	0.06	20	5	186	4000
Open Area	2363	0.06	15	5	217	3000
Totals					**1951**	**47400**

Fourth Floor						
Room	**Area**	**CFM/ft^2**	**Occupants**	**CFM/person**	**Ventilation CFM**	**Latent Load BTUH**
Tech Suite 1	164	0.06	6	5	40	1200
Tech Suite 2	164	0.06	6	5	40	1200
Tech Suite 3	158	0.06	6	5	39	1200
Classroom 1	625	0.12	35	10	425	7000
Classroom 2	669	0.12	40	10	480	8000
Classroom 3	678	0.12	40	10	481	8000
Conference Room 1	306	0.06	14	5	88	2800
Conference Room 2	379	0.06	14	5	93	2800
Lecture Hall 1	1136	0.06	100	7.5	818	20000
Lecture Hall 2	1597	0.06	200	7.5	1596	40000
Entrance	1365	0.06	15	5	157	3000
Open Area	2157	0.06	15	5	204	3000
Totals:					**4462**	**98200**

Appendix K - Psychrometric Chart

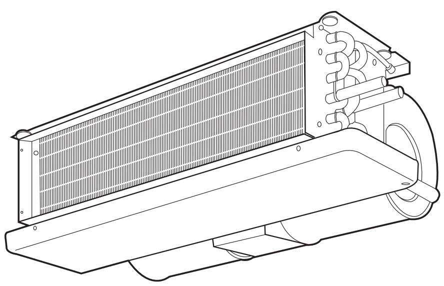


Carrier
United Technologies

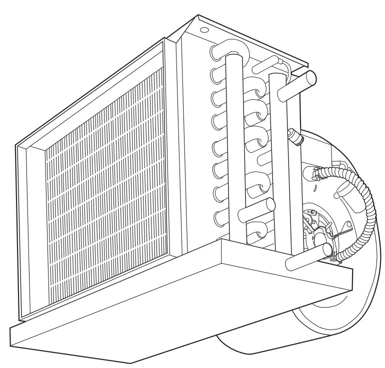
Product Data

42C,D,S,V Series Fan Coil Air Conditioners

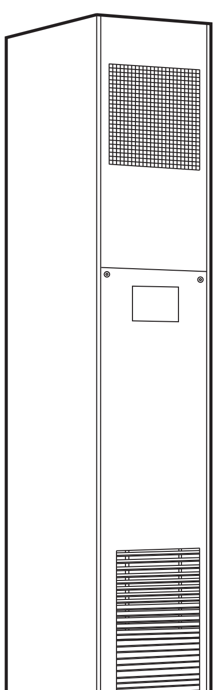
150 to 2000 cfm



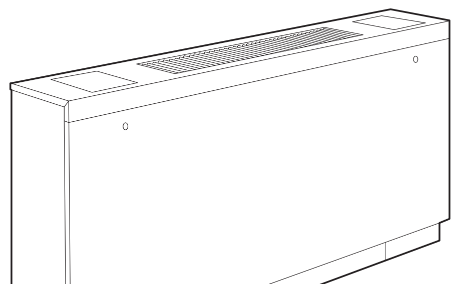
42CA HORIZONTAL



42DA DUCTED



42SH STACK



42VBC VERTICAL

Carrier's 42C,D,S,V Series fan coil units offer:
- Design flexibility, occupying minimum space
- Easy, low-cost installation
- Permanent split capacitor or electronically commutated motors deliver peak operating efficiency
- High performance, low cost
- Greater zone comfort control

Features/Benefits

Carrier's extensive range of superior fan-coil units combine design flexibility with easy, low-cost installation.

Versatility

With Carrier's 42 Series fan coils, you can select from 4 horizontal, 6 vertical, 5 ducted or 5 stacked models; furred-in or cabinet style, slant top or low silhouette, in 150 through 2000 cfm capacities. Coils are available with up to 5 rows (depending on model), to satisfy a variety of application requirements. The units are ideal for installation in motels, apartments, and other multi-room buildings. Many optional control packages are available to facilitate the following modes of operation: 2-pipe heating and cooling, 2-pipe heating and cooling with auxiliary electric heat, 2-pipe cooling with total electric heat, and 4-pipe heating and cooling. The control package offering includes 24-v or line voltage thermostats and BACnet* communicating controls.

Casings and frame are fabricated from tough, heavy gage galvanized steel. Custom decorative colors allow the unit to blend with any interior design.

© Carrier Corporation 2016

Features/Benefits (cont)

Low-cost installation and operation

Each unit is designed to occupy a minimum space. No complex system controls are required for Carrier fan coil units. Piping, drain, and wiring connections are readily accessible and mounting holes and slots are pre-drilled to save installation time and field labor expense.

42 Series quality reduces service and maintenance expenses

All coils are factory leak tested at 300 psig air pressure with coil submerged in water. Condensate drain pans are available in stainless steel or heavy gage galvanized steel constructions, along with optional condensate overflow switches complying to the latest building codes. A variety of insulation types are available for energy savings, sound absorption and indoor air quality (IAQ) preservation.

Efficient operation

Blower wheels are centrifugal-type, forward curved, double width, and double inlet sized for maximum efficiency.

Quiet, dependable performance

All units are built to operate unobtrusively with quiet motors and fans. In addition, 1/2-in. thick sound-absorbing, insulation is used to line the cabinet.

42C Series horizontal, 42V Series vertical units

Carrier room fan coil units are constructed with insulation that absorbs operating sound. The rugged construction reduces vibration during operation.

Economical, three-speed fans deliver just the right amount of conditioned air for your comfort needs at any load, and each unit can be shut off when not in use. Optional electronically commutated motors deliver peak operating efficiency. By choosing Carrier units, you can match your application with a wide range of custom-designed options and accessories, including electric heat. Filters are cleanable or throwaway type.

Carrier room fan-coil units provide year-round comfort.

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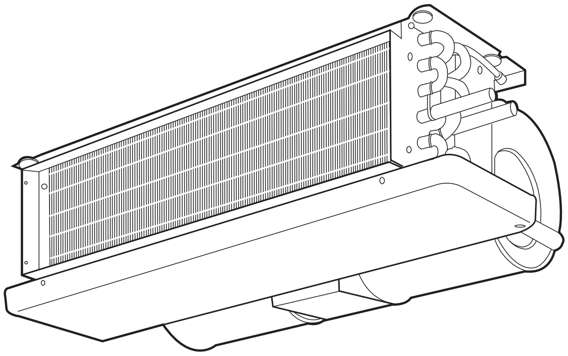
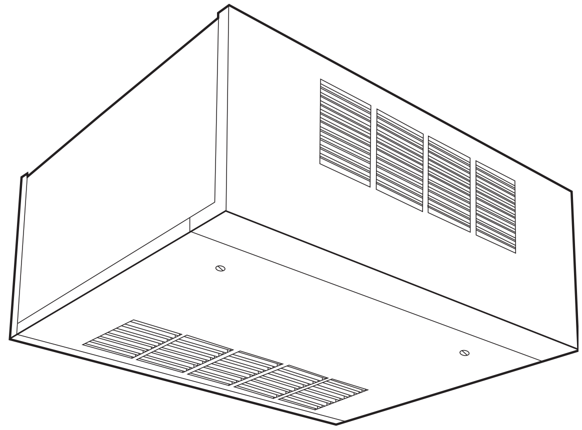
*BACnet is a Registered trademark of ASHRAE (American Society of Heating, Refrigerating, and Air-Conditioning Engineers).

Features/Benefits (cont)



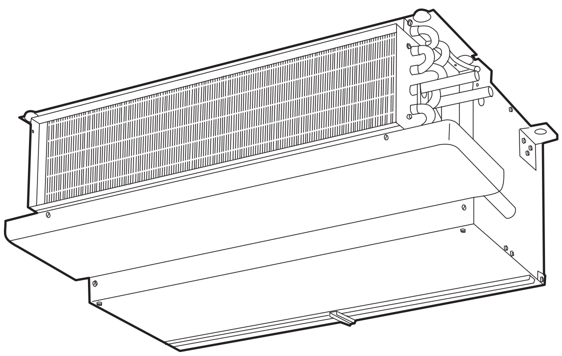
42CA

Furred-in ceiling model with low silhouette. (200-1200 cfm)



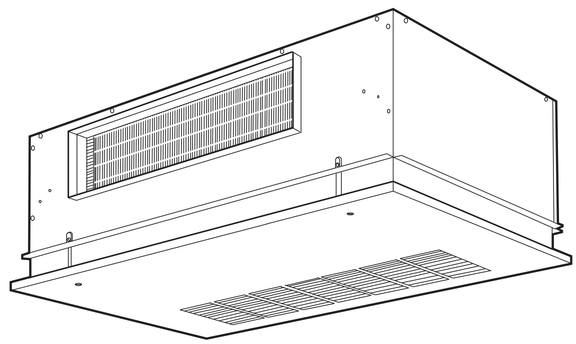
42CG

Cabinet model for under-ceiling mount with bottom or rear stamped louver return air grille. (200-1200 cfm)



42CE

Furred-in ceiling model with factory-installed plenum. (200-1200 cfm)



42CK

Cabinet model with telescoping flip-down panel and stamped louver bottom return or duct collar rear return. (200-1200 cfm)

Options

AVAILABLE OPTIONS

OPTIONS OR STANDARD FEATURES*	UNIT SERIES — 42																			
	Ceiling — Horizontal				Vertical Floor						Ducted — Horizontal					Stack — Vertical				
	CA	CE	CG	CK	VA	VB	VF	VC	VE	VG	DA	DC	DE	DF	DD	SG	SH	SJ	SU	SM
AIR VENT																				
Automatic Air Vent	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X		X
Manual Air Vent	Std	Std	Std	Std	Std	Std	Std	Std	Std	Std	Std	Std	Std	Std	Std	Std	Std	Std	Std	Std
CABINET CHANGES																				
Extended Cabinet Height								X	X											
Valve Compartment Extension, 10 in.										X										
COILS																				
2-Row (Cooling Only)	X	X	X	X				Std	Std	Std										
3-Row (2-Row Cooling, 1-Row Heating)								X	X											
3-Row (Cooling/Heating Only)	Std	Std	Std	Std	Std	Std	Std	X	X		X	X	X	X	X	Std	Std	Std	Std	X
4-Row (3-Row Cooling, 1-Row Heating)	X	X	X	X	X	X	X				X	X	X	X	X	X	X	X	X	X
4-Row (Cooling/Heating Only)	X	X	X	X	X	X	X				Std	Std	Std	Std	Std	X	X	X	X	Std
5-Row (Cooling/Heating Only)																				X
5-Row (4-Row Cooling, 1-Row Heating)	X	X	X	X	X	X	X				X	X	X	X	X	X	X	X	X	X
5-Row (3-Row Cooling, 2-Row Heating)	X	X	X	X	X	X	X				X	X	X	X	X	X	X	X	X	X
6-Row (4-Row Cooling, 2-Row Heating)											X	X	X	X	X					
6-Row (Cooling/Heating Only)											X	X	X	X	X					
7-Row (6-Row Cooling, 1-Row Heating)											X	X	X	X						
8-Row (6-Row Cooling, 2-Row Heating)											X	X	X	X						
Stainless Steel Coil Wrapper	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X		
OUTSIDE AIR OPTIONS																				
Motorized Damper					X	X	X									ETO	ETO	ETO		ETO
Manual Damper					X	X	X	X	X							X	X	X		X
Outside-Air Knockouts																			Std	
Outdoor-Air Connection		ETO	ETO	ETO				X	X			ETO	ETO	ETO	ETO					
DECORATIVE COLORS																				
Custom Colors Available Upon Request			ETO	ETO		ETO	ETO		ETO	ETO				ETO			ETO			
Arctic White Powder Coat Paint			Std	Std		Std	Std		Std	Std				Std			Std			
DISCHARGE OPTIONS																				
Stamped Discharge Grille			Std		Std	Std	Std		Std	Std										
Double Deflection Grille, Factory-Installed†			X		X	X	X		X					Std						
Double Deflection Grille, Shipped Loose†			X					X								Std	Std	Std	X	X
Discharge Duct Collar	Std	Std		Std				Std			Std	Std	Std		Std	Std	Std	Std		Std
Discharge Knockouts																			Std	
DRAIN PANS																				
Galvanized Drain Pan	Std	Std	Std	Std	Std	Std	Std	Std	Std	Std	Std	Std	Std	Std	Std	Std	Std	Std	Std	
Extended Drain Pan	X	X									X	X								
Stainless Steel Standard Drain Pan	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	Std
Stainless Steel Extended Drain Pan	X	X									X	X								
Tell-Tale Only	X	X	X	X							X	X	X	X						
Drip Lip Only	X	X	X	X							X	X	X	X						
Tell-Tell and Drip Lip	X	X	X	X							X	X	X	X						
HEATING OPTIONS																				
Electric Heater	X	X	X	X	X	X	X	X	X		X	X	X	X	X	X	X	X	X	X
Hot Water	X	X	X	X	X	X	X	X	X		X	X	X	X	X	X	X	X	X	X
Steam	ETO	ETO	ETO	ETO				ETO	ETO		ETO	ETO	ETO	ETO	ETO					

LEGEND

EC — Electronically Commutated
ETO — Engineered to Order
PSC — Permanent Split Capacitor
Std — Standard
X — Available as Options

*All options are factory-installed unless noted as shipped loose.
†Standard grille is steel; option is available as steel or aluminum.

AVAILABLE OPTIONS (cont)

OPTIONS OR STANDARD FEATURES*	UNIT SERIES — 42																			
	Ceiling — Horizontal				Vertical Floor						Ducted — Horizontal					Stack — Vertical				
	CA	CE	CG	CK	VA	VB	VF	VC	VE	VG	DA	DC	DE	DF	DD	SG	SH	SJ	SU	SM
FILTERS																				
1-in. Permanent Filters		X	X	X	X	X	X	X	X			X	X		X	X	X	X		
1-in. Throwaway Filters		Std	Std	Std	Std	Std	Std	Std	Std	Std		Std	Std	Std	Std	Std	Std	Std	Std	Std
1-in. MERV 7 Pleated												X	X		X					
1-in. MERV 8 Pleated		X	X	X	X	X	X									X	X	X	X	X
1-in. MERV 13 Pleated					X	X	X													X
2-in. MERV 8 Pleated					X	X	X													
2-in. MERV 13 Pleated					X	X	X													
LEVELING LEGS					X	X	X	X	X						X					
INSULATION																				
Foil Faced Insulation	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X		X
Fiberglass Insulation	Std	Std	Std	Std	Std	Std	Std	Std	Std	Std	Std	Std	Std	Std	Std	Std	Std	Std	Std	Std
Closed Cell Insulation		X	X	X	X	X	X	X	X	X										
Premium IAQ Fiberglass	ETO	ETO	ETO	ETO				ETO	ETO	ETO	ETO	ETO	ETO	ETO	ETO	ETO	ETO	ETO		ETO
MOTORS - PSC																				
115-1-60, 3-Speed	Std	Std	Std	Std	Std	Std	Std	Std	Std	Std	Std	Std	Std	Std	Std	Std	Std	Std	Std	Std
208-1-60, 3-Speed	X	X	X	X	X	X	X	X	X		X	X	X	X	X	X	X	X	X	X
230-1-60, 3-Speed	X	X	X	X	X	X	X	X	X		X	X	X	X	X	X	X	X	X	X
277-1-60, 3-Speed	X	X	X	X	X	X	X	X	X		X	X	X	X	X	X	X	X	X	X
220-1-50, 3-Speed	X	X	X	X	X	X	X	X	X		X	X	X	X	X	X	X	X		
MOTORS - EC																				
115-1-60	X	X	X	X	X	X	X	X	X		X	X	X	X	X	X	X	X	X	X
208-1-60	X	X	X	X	X	X	X	X	X		X	X	X	X	X	X	X	X	X	X
230-1-60	X	X	X	X	X	X	X	X	X		X	X	X	X	X	X	X	X	X	X
277-1-60	X	X	X	X	X	X	X	X	X		X	X	X	X	X	X	X	X	X	X
220-1-50	X	X	X	X	X	X	X	X	X		X	X	X	X	X	X	X	X	X	X
MOTOR QUICK-DISCONNECT PLUG	Std	Std	Std	Std	Std	Std	Std	Std	Std		Std	Std	Std	Std	Std	Std	Std	Std	Std	Std
INTEGRAL THERMAL OVERLOAD PROTECTION	Std	Std	Std	Std	Std	Std	Std	Std	Std	Std	Std	Std	Std	Std	Std	Std	Std	Std	Std	Std
RETURN AIR GRILLE, Shipped Loose																				
Stamped Return Grille			Std	Std		X	X		Std	Std						Std	Std	Std	Std	X
Hinged Panel														Std						
TAMPERPROOF LOCKS																				
Access Panels			Std	Std		Std	Std		Std				Std	Std		Std	Std	Std	Std	Std
Control Access Doors						X	X		X											
VALVE PACKAGES	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
WIRING PACKAGES	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X

LEGEND

EC — Electronically Commutated
ETO — Engineered to Order
PSC — Permanent Split Capacitor
Std — Standard
X — Available as Options

*All options are factory-installed unless noted as shipped loose.
†Standard grille is steel; option is available as steel or aluminum.

Options (cont)

Factory-installed options

Coils — Choice of a 2-pipe or 4-pipe system with the following chilled/hot water coil configurations:

COIL CONFIGURATION	UNIT			
	42C	42D	42S	42V
2-Row Coil	•	ETO	ETO	—
3-Row Coil	•	•	•	42VAC, VBC, VCA,VEA, VFC only
4-Row Coil	•	•	•	42VAC, VBC, VFC only
5-Row Coil	—	—	42SM only	—
6-Row Coil	—	•	—	—
8-Row Coil*	—	ETO	—	—
Opposite End Coil Connections				
3/1	•	•	•	42VAC, VBC, VFC only
3/2	•	•	•	42VAC, VBC, VFC only
4/1	•	•	•	42VAC, VBC, VFC only
4/2	—	•	—	—
6/1	—	42DA,DC, DE,DF only	—	—
6/2	—	42DA,DC, DE,DF only	—	—
Same End Coil Connections				
2/1	—	—	—	42VCA, VEA only
3/1	•	•	•	42VAC, VBC, VFC only
3/2	•	•	•	42VAC, VBC, VFC only
4/1	•	•	•	42VAC, VBC, VFC only
4/2	—	•	—	—
6/1	—	42DA,DC, DE,DF only	—	—
6/2	—	42DA,DC, DE,DF only	—	—
Cu/Cu Coil Special Option*	ETO	ETO	ETO	ETO

LEGEND

- • Available
- — Not Available
- ETO Engineer to Order

*Needs quote control.

Seismic compliance options — Several models have been tested and approved for installations requiring IBC or OSHPD seismic certification. Submit special quote for verification of unit compliance.

Condensate overflow switch — This switch shuts down the unit when the water level in the drain pan reaches an unsafe level. Building code changes in many locales now require this type of device.

Decorative colors — Standard color is Arctic White. Custom colors may be provided when matched with a provided paint chip. Special quote required for custom colors.

Decorative colors may be applied to:

- Cabinet of 42VBC, VFC, VEA, VGA
- Cabinet of 42CG
- Panels of 42SH
- Bottom panels of 42CK
- Cabinet of 42DF

Electric heaters — Coils are of high grade single-phase, nichrome resistance wire, insulated by ceramic insulators in plated steel brackets. Heater sizes available are shown in the application data section for the respective units. Not available on 42VGA units.

Filters — Each unit (except the 42CA, DA units) includes a non-woven synthetic throwaway filter sized for low velocity and maximum efficiency. The standard option will filter both return and outside air. For optional filters, please refer to available option table on pages 8 and 9.

Fusing — Incoming power fusing, as well as blower motor and control sub-fusing for units that use electric heat. The blower motor and control sub-fusing (single power source wiring) is required when single source power with electric heat is specified.

Manual air vents — Each standard coil includes a manual air vent to allow venting at the coil if necessary for quick, complete air elimination.

Motors — Three-speed PSC (permanent split capacitor) motors are offered as standard, providing the ability to adjust airflow to meet varying load conditions. High-static PSC motors are available as an option for applications requiring higher external static capability. ECM (electronically commutated) motors are optional on all units except 42VG. ECM motors offer programmable features, low sound, and increased energy efficiency. Refer to the application data section for more information on ECM control methods.

Outside-air opening/damper — Damper is adjustable from 0 to 25% and provides ventilation air to unit. (Manual/motorized damper available on 42SG, SH, SJ, SM units.)

Service switches — Concealed service switches are available for use by maintenance and service personnel to shut off the power while working on the unit.

Single power source connection — Factory-installed junction box allows use of single power source for motor and heater when they are of the same voltage.

Stamped toe space return-air grille — The return-air grille is available as a factory-installed option for 42VBC and 42VFC units.

Tamperproof fasteners (Allen head) — Tamperproof fasteners are installed on the access panels and are available for all cabinet model units.

Thermostat control packages — We offer a variety of control devices to meet the most basic to the most demanding operating logic. All of our control schemes utilize 3-speed fan control to modulate cooling output, maximize the percentage of latent heat removal, and to further reduce the sound level when maximum cooling and heating performance is not required. The standard thermostat control option is line voltage except on 42SU and 42SM, which include a low voltage control package as standard. Unit-mounted line voltage and 24-v thermostats are available on the 42V Series units. For thermostat control package options refer to pages 13-15.

Field-installed accessories

Automatic air vents — Automatic air vents have fiber washers which allow air in the pipes to pass through, automatically bleeding the system, and eliminating the need to manually remove air from the system. When wet, washers swell and seal the system.

Drip lips (removable drain extension) — Drip lips are frequently used when valves are added after unit installation and space limitations will not permit use of an extended drain pan. The drip lip is placed on the end of the drain pan and is pitched toward the pan to ensure proper drainage. The drip lip gives positive control of condensate from valves and controls.

Panels, frames, and grilles — Panels, frames, and grilles on the 42S Series units can be chosen in a wide variety of combinations to suit room decorating requirements and allow access to the unit for maintenance. Discharge grilles are double deflection type, aluminum finish or painted. Return-air access panels containing return-air grilles are available in five different types as illustrated on pages 102 and 103.

PANELS, FRAMES AND GRILLES

PANEL NO.	DESCRIPTION
1	Standard, heavy gage galvanized steel. Coated with powder-coat Arctic White finish. Attached to unit with $^{1}/_{4}$ turn fasteners.
2	Heavy gage galvanized steel. Coated with powder-coat Arctic White finish. Includes access door for concealed unit-mounted controls.
3	Bar-type extruded aluminum with frame matching double deflection supply grille. Fastens to wall and unit with $1^{1}/_{2}$ in. long screws.
4 and 5	Heavy gage galvanized steel. Coated with powder-coat Arctic White finish. Frame mounted on sheetrock with screws. Panel mounted in frame with $^{1}/_{4}$ turn fasteners.
All	Each panel provides access to all internal components.

Return-air grilles — Stamped-type return-air grilles are standard on 42CG,CK,VE,VG,SG,SH,SJ,SU units and optional on 42VBC,VFC,SM units. Anodized aluminum hinged bar-type grilles are installed on 42DF units.

Risers — The 42S Series units can accommodate $^{3}/_{4}$-in. (supply and return) and 1-in. (drain) to $2^{1}/_{2}$-in. riser sizes in 2-pipe systems. For other applications, such as reverse return risers or 4-pipe systems, it may be necessary to accommodate the additional risers.

Condensate drains are available in sizes down to 1-in. for greater cost economy. Riser size-reducers are factory-installed on 42SG, SJ, and SH. For risers over 119-in. long, extension pieces can be furnished for field installation.

NOTE: Risers for the 42SU,SM units are shipped separately for field installation and testing before the unit is installed.

Riser expansion — The 42S Series units are built to accommodate modest expansion of the external riser. This only allows for expansion between the unit and the riser. This allowance for movement within the unit is not intended to replace necessary riser expansion compensation devices that the consulting engineer may deem advisable for the external riser system. External riser expansion/contraction compensation and anchoring are the responsibility of the consulting engineer and the installing contractor.

Risers material and insulation — The 42S Series unit supply, return, and drain risers can be furnished in type M or L copper. All factory-furnished risers are insulated with flexible closed foam insulation in $^{1}/_{2}$-in. or $^{3}/_{4}$-in. thickness.

Discharge grilles — Two types of double deflection discharge grilles are available for 42CG, VBC, VFC, VEA units; an integral steel grille painted to match the unit or a separate unpainted anodized aluminum grille. Optional discharge air grilles for 42S Series units are suitable for sidewall application, and available in clear anodized aluminum or Arctic White finish. The aluminum discharge grilles are suitable for air dry field painting. The discharge grille frame and blades are 6063 extruded aluminum alloy with 200-R1 satin anodized finish. The frame has a typical wall thickness of 0.050-in. and is separated from the blades with injection-molded nylon bushings. This method of assembly minimizes corrosion and vibration. The frame mounting holes are dimpled, allowing for a counter-sunk fastener head appearance. All blades are airfoil in design, individually adjustable and spaced $^{3}/_{4}$-in. on center. At the outer edge of the frame is a specifically engineered channel which retains an extruded flexible vinyl bulb gasket that produces a positive air seal at the mounting surface, minimizing smudging. An optional opposed blade damper is screwdriver operated through the face of the unit and has the same extruded aluminum construction and injection-molded nylon bushings. The unit achieves an effective area of 80% with the blades set at a 0 degree pattern, thus eliminating high velocity and pressure drop at the grille face. Wider deflection with reduced throw may be achieved at the 22 and 45 degree blade settings with slightly increased sound levels.

Tell-tale drain pan — A secondary drain connection is located above the primary drain to act as a “tell-tale” in the event that the primary drain becomes obstructed. They can be applied to either the main drain pan or an extended main drain pan. This option is only available on the 42C and 42DA, DC, DE, DF units.

Thermostats control packages — Wall-mounted line voltage and 24-v thermostats are available on the 42 Series fan coil units. For thermostat control packages options refer to pages 13-15.

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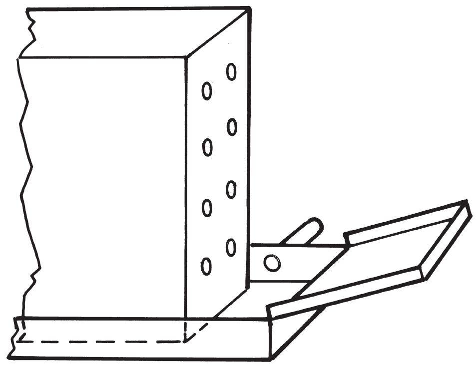
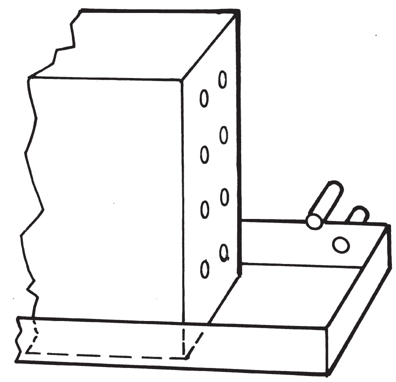
Options (cont)

DRIP LIP
(Horizontal Unit)



“TELL-TALE” DRAIN PAN
(Horizontal Unit)



Controls

Use the Control Selection Guide table to make sure that all necessary components are provided for and that the components are compatible with the required control system.

NOTE: When thermostatic fan control is selected or when unit outside-air dampers are used, unit-mounted thermostats are not recommended as their use will result in poor room temperature sensing.

CONTROL SELECTION GUIDE

SYSTEM		DESCRIPTION	THERMOSTAT	CHANGEOVER ON SUPPLY PIPE	VALVE	FAN SWITCH	NOTES
2-PIPE HEATING-COOLING*	**Fan Control (2-pipe)**	Fan manually cycled	None	None	None	3-Speed switch	Not recommended for high humidity application
	Two-Position Electric Valves (2-pipe)	Thermostat cycles valve open or closed.	Wall or unit mounted includes heat-cool switch.	None	Motorized (N.C.) 3-way or 2-way, no bypass required.	Thermostat has integral 3-speed switch	Valve packages with belled end(s) for field soldering to coil.
		Thermostat cycles valve open or closed. Mode automatically switched by changeover sensing water temp.	Wall or unit mounted. Heating/cooling Thermostat	Yes	Motorized (N.C.) 3-way or 2-way	Thermostat has integral 3-speed switch	
ELECTRIC HEAT	**Two-Position Electric Valve with Auxiliary Electric Heat (2-pipe)**	Thermostat cycles valve open or closed. Thermostat activates electric heater. Heater cannot turn on if hot water is in coil.	Wall or unit mounted. Sequenced heating and cooling.	Yes. Two Required.	Motorized 3-way or 2-way	Thermostat has integral 3-speed switch	Valve packages with belled end(s) for field soldering to coil.
	Two-Position Electric Valve with Total Electric Heat (2-pipe)	Thermostat cycles valve open or closed.Thermostat activates electric heater.	Wall or unit mounted. Sequenced heating and cooling.	None	Motorized (N.C.) 3-way or 2-way, no bypass required	Thermostat has integral 3-speed switch	Valve packages with belled end(s) for field soldering to coil.
4-PIPE	**Two-Position Electric Valves (4-pipe)**	Thermostat cycles cooling valve open or closed. Thermostat cycles heating valve open or closed.	Wall or unit mounted. Sequenced heating and cooling.	None	Motorized (N.C.) 3-way or 2-way (requires 2 valves)	Thermostat has integral 3-speed switch	Valve packages with belled end(s) for field soldering to coil.

LEGEND

N.C. — Normally Closed

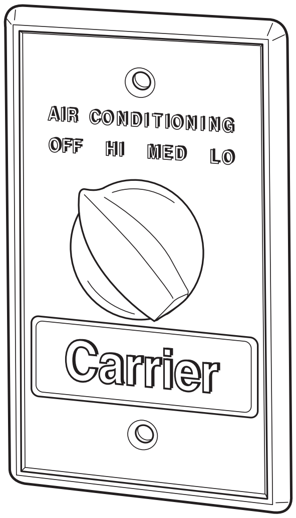
*If system is HEATING-ONLY or COOLING-ONLY, no changeover or bypass is required.

NOTE: Unit-mounted thermostats are not recommended with either fan-cycle control or applications with outside-air dampers.

Controls (cont)

Remote-mounted controls

3-SPEED SWITCH



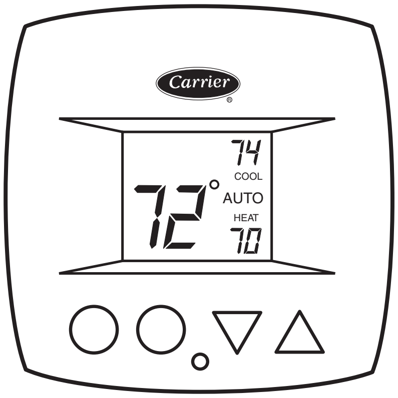
Wall mounted 3-speed switch — This switch has 4 positions: OFF, HIGH, MEDIUM, and LOW. Switch has auxiliary contact that is energized when switch is in HIGH, MEDIUM or LOW position.

Some of the options common with the 3-speed switch are:

1. Unit-mounted switch on furred-in vertical model. (Available as special order on horizontal models.)
2. Switch without OFF position.

Optional remote-mounted thermostat or unit-mounted 24-v thermostat

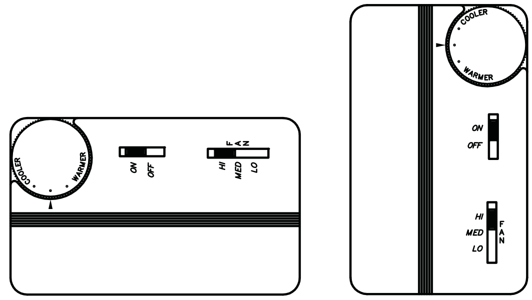
24-V DEBONAIR® THERMOSTAT



24-v Debonair thermostat — Features large Thermo-glow™ display, Neverlost™ memory, Smart Fan™ dynamic fan speed control, 4-pipe, 2-pipe automatic changeover applications with adjustable dead band. Programmable and non-programmable models available.

Optional remote-mounted line-voltage thermostat

LINE VOLTAGE T155 THERMOSTAT



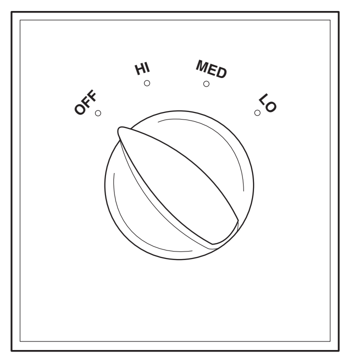
Line voltage T155 thermostat — Features 50 to 90 F temperature range, manual 3-speed fan control, mount is a standard 2 x 4 in. box, 4-pipe, 2-pipe and autochangeover applications. Available in vertical or horizontal styles.

Unit-mounted controls

Line voltage controls by others — Unit supplied with wiring for valve cycle operation, including changeover sensors (as required) for use with field-installed line voltage thermostats.

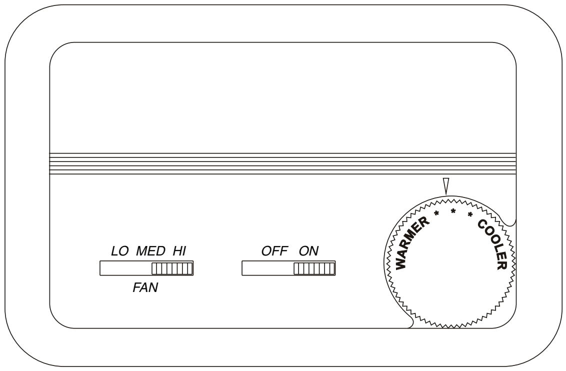
24-v controls by others — Unit supplied with factory-installed 24-v transformer, 3-speed relay board, and aquastat (as required) for use with field-installed low voltage controls.

3-SPEED SWITCH

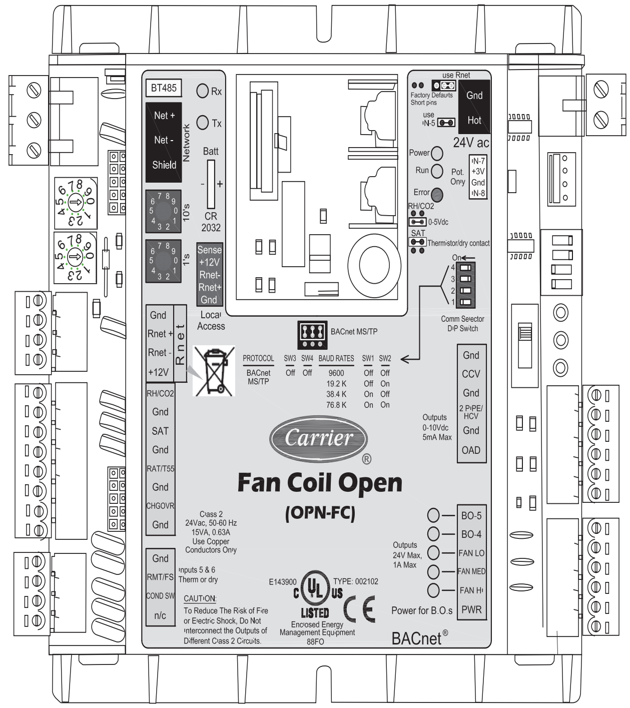


Unit-mounted 3-speed switch — Switch has OFF, HIGH, MED and LOW positions. Switch is also equipped with auxiliary connection energized when switch is in HIGH, MED or LOW position.

T156 THERMOSTAT



FAN COIL OPEN CONTROLLER



Line voltage T156 thermostat — Includes thermostat for 2-pipe or 4-pipe system and manual 3-speed fan control. The special combination allows for the fan coil unit to have control for the valve cycle only. This thermostat is only available for unit-mounted line voltage applications.

Integrated Direct Digital Controls (DDC)

Fan Coil Open controller — The factory-mounted controller continuously monitors and regulates the fan coil operation with reliability and precision. This advanced controller features a sophisticated, factory engineered control program that helps provide optimum performance and energy efficiency. The fan coil open controller also features plug-and-play connectively to Carrier's i-Vu® Open control system. For added flexibility, the fan coil controller is capable of stand alone operation, or can be integrated with any Building Automation System (BAS) utilizing BACnet protocol. Application features include built-in advance control routines for zone level humidity control, zone level demand ventilation (ASHRAE 62) and automatic fan speed control based on demand. System benefits include demand limiting for maximum energy saving, and compatibility with i-Vu control system tenant billing for tracking tenants after hours energy usage. Hardware features include onboard hardware clock, remote occupancy input, and support for space temperature thermistor sensor for stand alone operation.

Controls (cont)

Automatic changeover (Summer-Winter switch) — The automatic-changeover thermostat sensor is a 10,000-ohm thermistor (33ZCSENCHG) in a moistureproof and dust-proof enclosure. Cable and temperature sensing element are hermetically sealed in a polypropylene enclosure with epoxy resin. Device clamps on coil supply pipe with end snap-on clip.

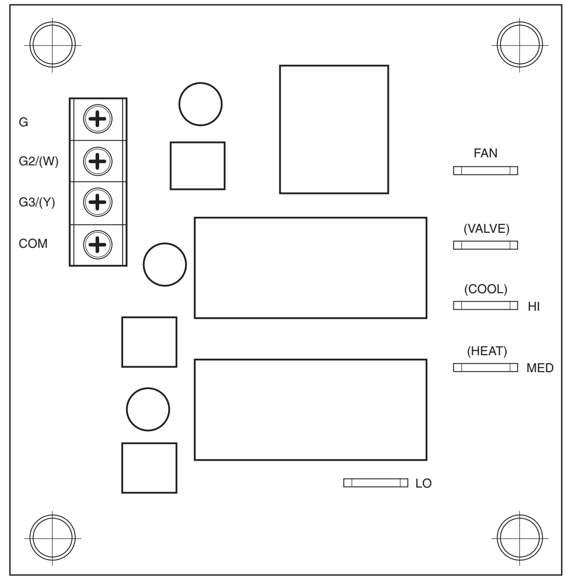
The set point temperatures are factory set. When water temperature rises above 80 F (approximately), the sensor switches to the winter cycle. When water temperature drops below approximately 70 F, the sensor switches to the summer cycle. Switch reset is automatic.

Fan coil control relay board — The fan coil relay board is used in conjunction with the Debonair thermostat or a controller or the Fan Coil Open controller to regulate a single-speed or multi-speed fan. The fan coil relay board can also be used to connect the fan coil controller to a line voltage valve actuator.

The fan coil relay board is factory shipped as a PC board with four $^1/_2$-in. stand-offs attached for field mounting.

NOTE: One fan coil relay board is used for each application. Fan coils with two or more fan motors use a fan coil relay board for each fan motor. A maximum of three fan coil relay boards can be wired to one fan coil control.

FAN COIL CONTROL RELAY BOARD



Selection procedure

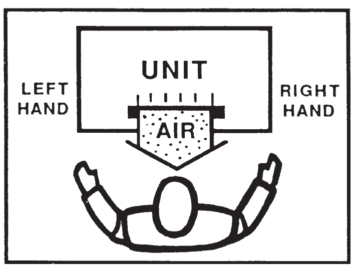
Refer to the Carrier Electronic Selection Program for information to determine unit sizing for your needs.

Application data

Basic definitions

Unit hand — When facing the supply air outlet from the front of the unit (air blowing in your face), your right hand will be the right hand side of the unit and your left hand the left hand side of the unit.

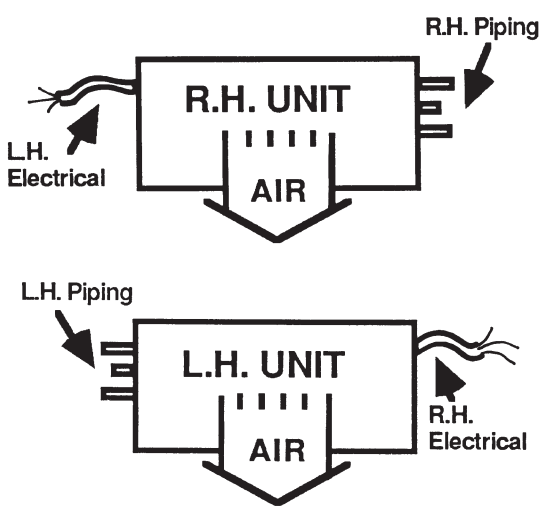
UNIT HAND



Same end connection (2 pipe or 4 pipe) — All piping connections are on the same end (side) of the unit. Controls and electrical connection will be on the end (side) opposite the piping connection.

Standard 2-pipe units will be the same end connection.

SAME END CONNECTION

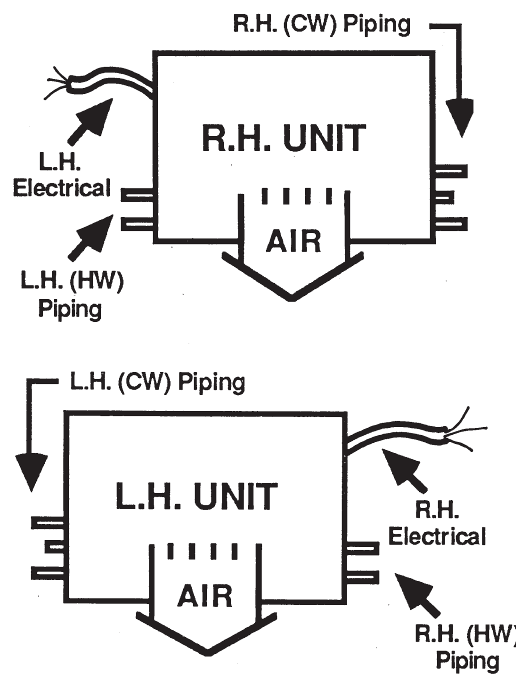


NOTE: Piping determines the hand of the unit.

Opposite end connection (4-pipe option) — Hot water (HW) piping connections and electrical will be on the end (side) opposite the chilled water (CW) and drain connections.

4-Pipe coil arrangement — For 4-pipe coil combination chilled water/hot water coils, the hot water coil is in the reheat position. For 4-pipe combination DX (direct expansion)/hot water coils, the hot water is in the preheat position. The opposite hot water coil position is available through quote control.

OPPOSITE END CONNECTION



NOTE: Chilled water piping determines the hand of the unit.

Application data (cont)

System piping

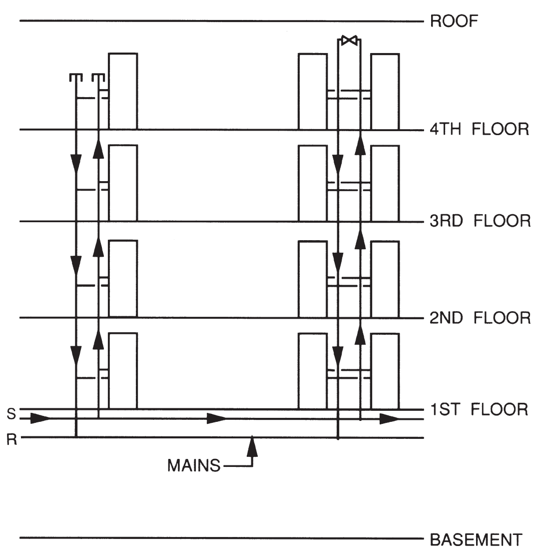
The following diagrams show some common methods used to pipe the 42S Series units. Only the 2-pipe systems are shown; however, the methods would be the same for 4-pipe systems.

System 1, the "direct return" system, is the most common. It is economical to install since it supplies and returns the water for a riser column from the same location, at the top or the bottom of a building. This type of riser arrangement does require more attention to individual unit water flow balancing. The risers are normally capped at the end as shown in the diagrams.

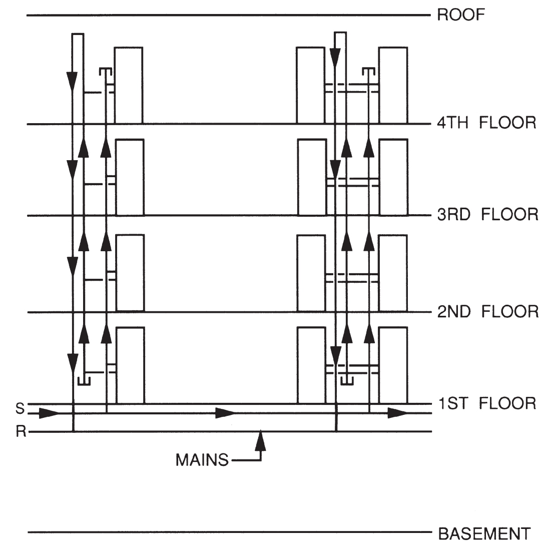
System 2, the "reverse return" system, is used to minimize the requirement for individual unit balancing. This system is usually referred to as the self-balancing system. The arrangement of the risers allows the water flow for each unit in a column to be equalized. In the reverse return system both the supply and return mains are located at the top or the bottom of a building requiring an additional return riser to be furnished in the units.

System 3, the "common reverse return" system, typically has the supply and return mains located remotely from each other — such as one at the top and one at the bottom of a building. This eliminates the need for a reverse return riser in the units.

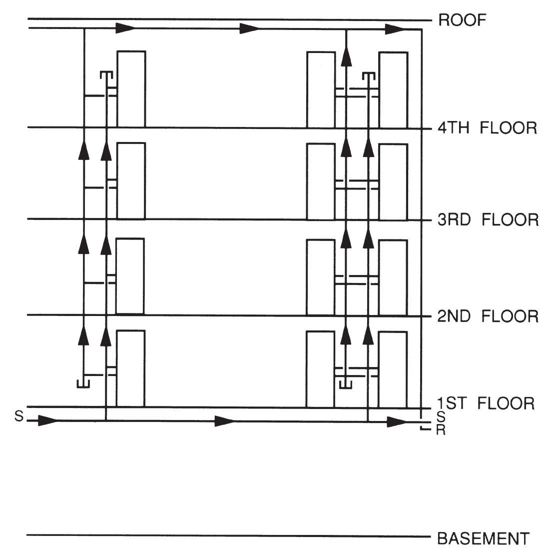
SYSTEM 1 — DIRECT RETURN



SYSTEM 2 — REVERSE RETURN



SYSTEM 3 — COMMON REVERSE RETURN



Risers (42S units)

Riser diameter is an important consideration in the design of stack series systems. Standard units can accommodate $^3/_4$-in. to $2^1/_2$-in. riser sizes in 2-pipe systems. For other applications, such as reverse return risers or 4-pipe systems, it may be necessary to accommodate the additional risers.

Riser size is based on the water flow needed for a given tier of units. Unit risers are sized according to the diameter and length requirements as specified by the customer. To determine riser size, water velocity should be limited to 5 to 8 ft per second. Thus, if 10 units are to be stacked vertically with each unit requiring 3 gpm, the maximum flow in the risers is 30 gpm. Through $1^1/_4$ in. risers, this is a velocity of 7.5 ft per second. The maximum flow rate of 30 gpm occurs only at the supply and return points. As the water moves upward, the flow in the supply riser is reduced by 3 gpm per floor, so that after 3 floors, the total flow is 21 gpm and riser size can be reduced to one inch. See the Main Riser Pressure Drops chart on page 111.

Condensate drains are available in sizes down to 1 in. for greater first cost economy.

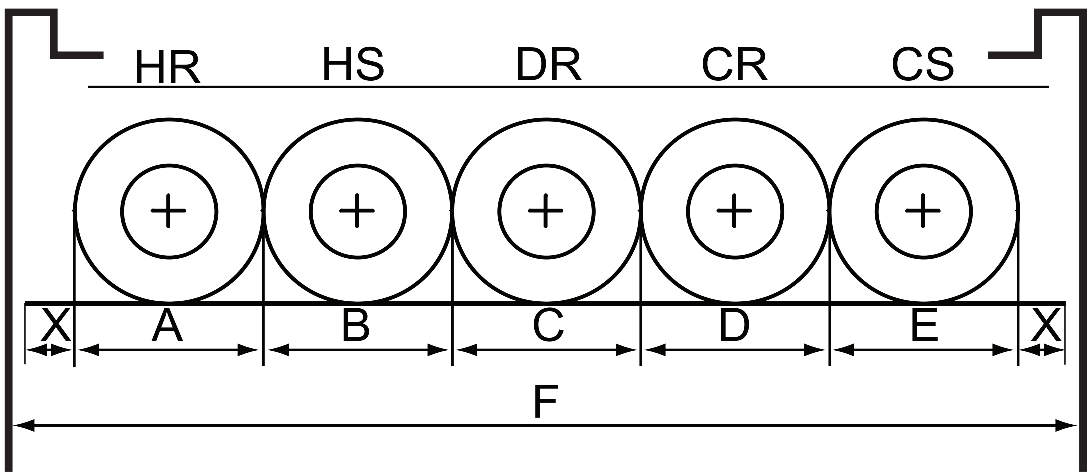
Riser size-reducers are factory installed and caps are provided at customer request except for 42SU units.

For risers of over 119 in. length, extension pieces can be furnished for field installation.

Typical arrangements

Typical arrangement applications for each model type are shown on page 20. The fan coil units feature almost an unlimited number of arrangements to meet the needs of new construction, renovation, or reconstruction. Consult the factory for the arrangement (standard or special) to meet your particular need.

MAXIMUM RISER DIAMETER DIAGRAM



UNIT SIZE	F DIMENSION
03,04	17 in.
06,08	20 in.
10,12	24 in.

LEGEND

CR — Cold Water Return
CS — Cold Water Supply
DR — Drain
HR — Hot Water Return
HS — Hot Water Supply

NOTES:
1. The F dimension is determined by the following formula: X + A + B + C + D + E + X = F (where X = $^7/_{16}$ in.)
2. The largest diameter riser in each tier must be able to fit in the smallest size cabinet and not exceed the F dimension.
3. For unit sizes 14-20, contact application engineering.

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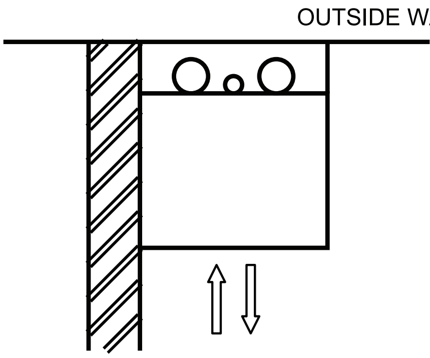
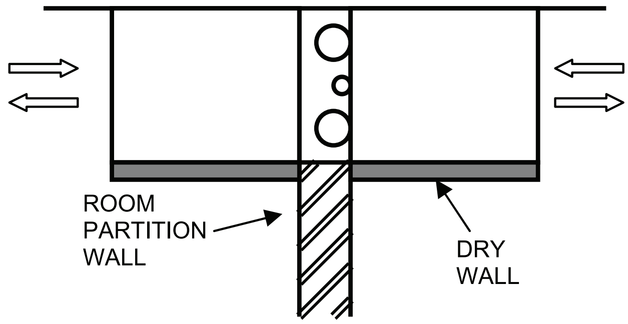
Application data (cont)

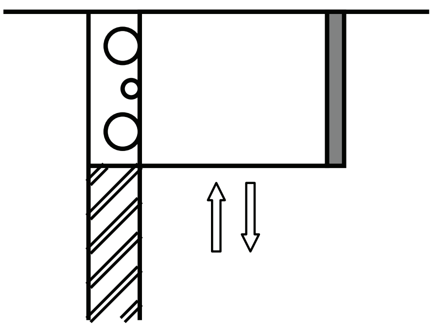
TYPICAL ARRANGEMENT APPLICATIONS



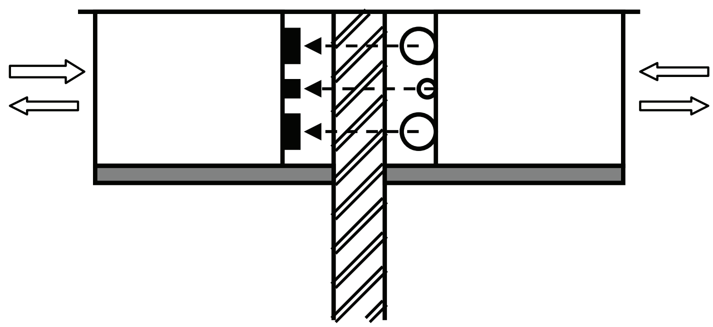
42SH – EXPOSED CABINET



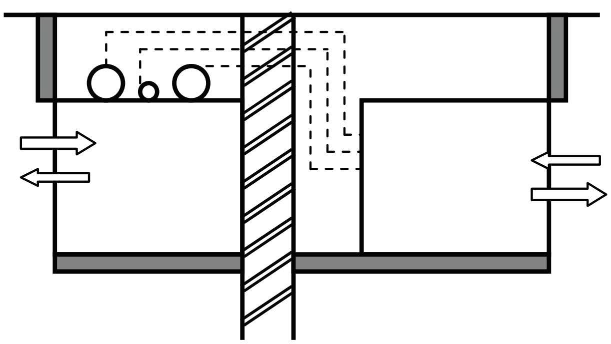
42SJ – BACK-TO-BACK FURRED-IN STACK



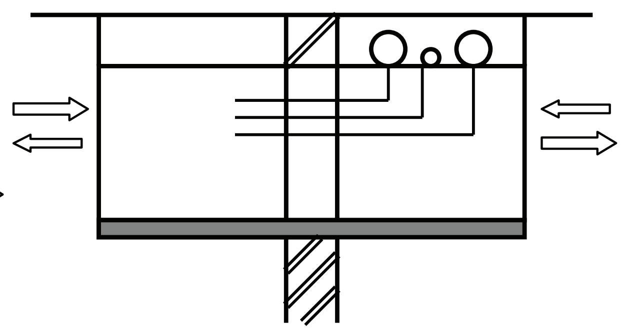
42SG – FURRED-IN STACK



42SG – FURRED-IN STACK MASTER/SLAVE



42SG – FURRED-IN-STACK X-MASTER



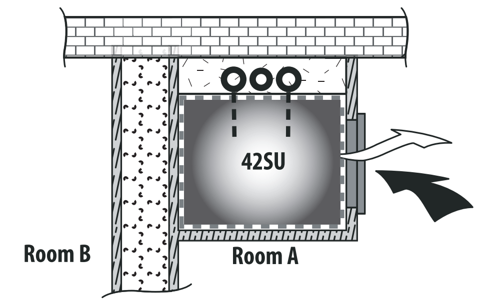
42SG – FURRED-IN-STACK SIAMESE

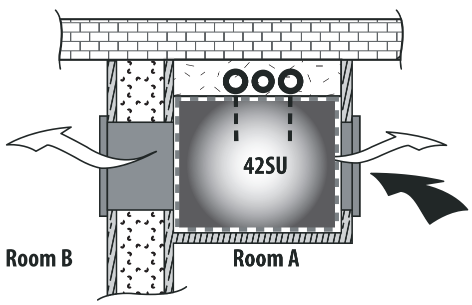
42SU ARRANGEMENT OPTIONS

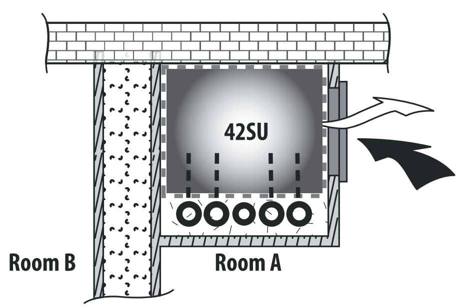
One of the unique traits of the Universal Stack (42SU) is the variety of possible unit arrangements. The best unit design configuration can be selected by choosing from numerous unit arrangement options that utilize knockout designs while conserving floor space and reducing installation costs.

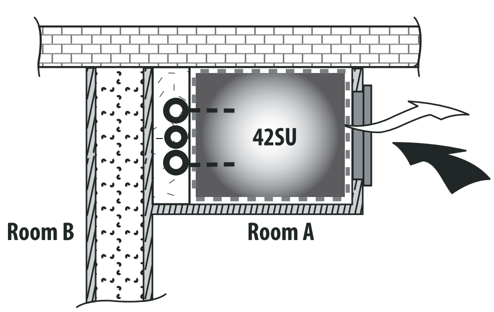
Below are just a few pictorials of the many arrangement possibilities of the 42SU fan coil system.

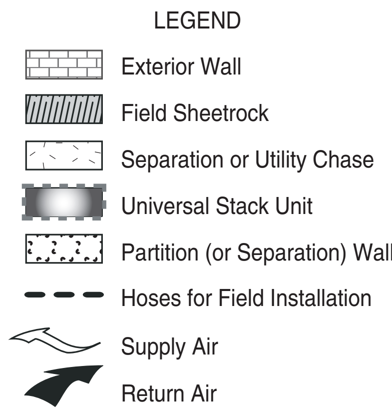
NOTE: Risers ship separately. Units are field connected to risers using factory furnished flex hoses.



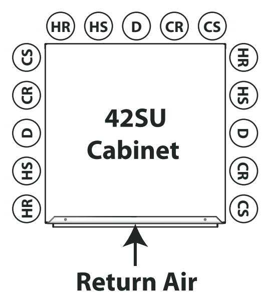






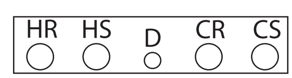


The Supply, Return, and Drain risers (2-pipe or 4-pipe applications) can be oriented on any of three sides of the unit.



R = Return
D = Drain
S = Supply

2-pipe



HR = Hot Water Return
HS = Hot Water Supply
D = Drain
CR = Cold Water Return
CS = Cold Water Supply

4-pipe

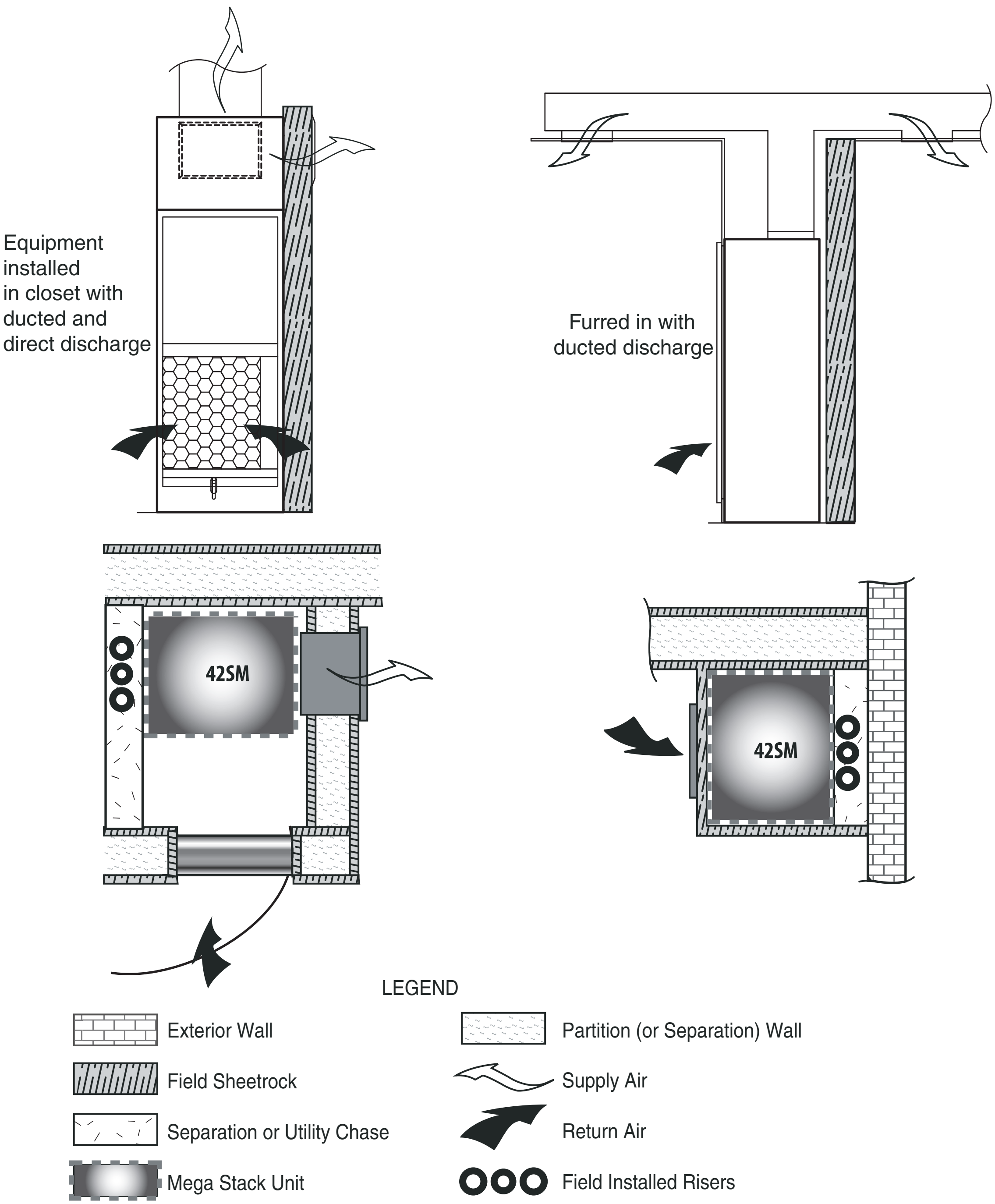
Application data (cont)

42SM UNIT CONFIGURATION OPTIONS

Mega Stack units (42SM) are designed to be installed either in a small mechanical closet or furred in with drywall adhered directly to the cabinet. One of the unique traits of the 42SM unit is its optional discharge plenum. The discharge plenum is a factory-installed option that adds 22-in. to the unit height and provides multiple air duct or supply-air grille connections.

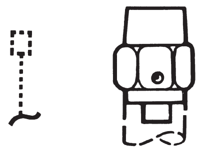
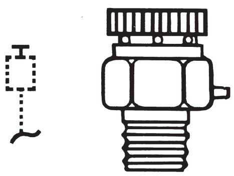
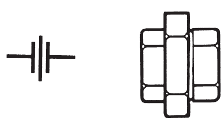
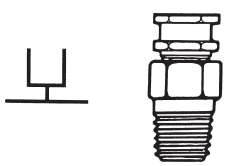
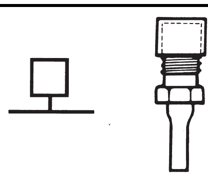
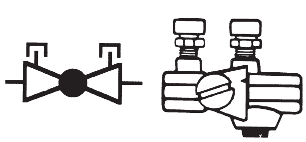
The designer is afforded the luxury of specifying a single unit, which can duct to multiple spaces, direct discharge to a single space, or provide a combination of the two. If necessary, the plenum can be added or removed in the field to accommodate design changes.

Below are a few of the many arrangement possibilities of the 42SM fan coil system.



NOTE: Risers ship separately. Units should be field connected using factory furnished flex hoses.

PIPING COMPONENTS

SYMBOL/SKETCH	DESCRIPTION	C_V FACTOR		RATING*		STEAM USE
		1/2	3/4	PSI	F	
	**MANUAL AIR VENT:** Threaded brass needle valve with screwdriver slot for adjustment. Application — Body brazed into high point of heating and cooling coils for bleeding air from coil. Standard item on all hydronic coils (not used on steam or DX coils). Should not be used in lieu of main system air vents.	N/A	N/A	400	100	NO
	**AUTOMATIC AIR VENT:** Nickel plated brass valve, fiber-disc type, with positive shut-off ball-check and quick vent feature via knurled vent screw. Application — Optional replacement for manual air vent. Automatically passes minute quantities of air through the fiber discs which expand upon contact with water, completely sealing the valve. As air accumulates, the fiber discs dry and shrink, repeating the cycle. Not recommended for removing large quantities of air encountered during initial start-up or subsequent draining and refilling. Should not be used in lieu of main system air vents.	N/A	N/A	125	240	NO
	**SWAGE:** Copper tube end expanded to accept a copper tube of the same size for factory or field brazing. Application — Used where possible for all tubing joints for best joint integrity.	N/A	N/A	300	200	YES
	**UNION:** Combination wrought copper/cast brass union assembly, solder by solder. Application — Used for quick connect (and disconnect) of valve package components to minimize field labor and facilitate servicing of unit.	N/A	N/A	300	200	YES
	**INSERTION TEST PORT:** Brass body valve for acceptance of test probe (up to 1/8 in. diameter). Application — Installed on one (or both) sides of the coil to allow for temperature or pressure sensing. Used for close tolerance water balancing and service analysis.	N/A	N/A	250	250	NO
	**PRESSURE TEST PORT:** Brass body 1/4 service access fitting with removable depressor type core. Application — Installed on both sides of the coil to allow for pressure sensing. Attach pressure gages to facilitate close tolerance water balancing.	N/A	N/A	400	210	NO
	**CIRCUIT SETTER:** Variable water flow balancing valve with manual adjustment knob, pointer, percent-open scale, memory stop and integral pressure read-out ports. Application — Used for close tolerance water flow balancing. Positive shut-off ball valve feature allows usage as combination balancing and shut-off valve.	2.12	3.9	300	250	NO

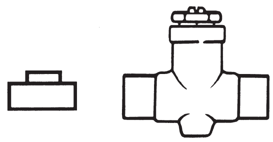
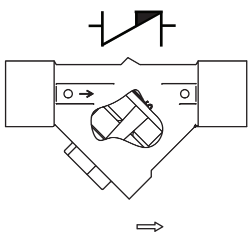
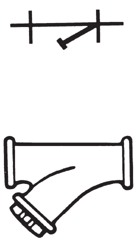
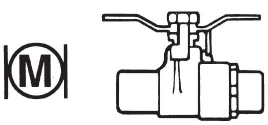
LEGEND

Cv — Coefficient of Velocity
DX — Direct Expansion
ETO— Engineering to Order

*Check all system component pressure ratings (coils, values, pumps, etc.) with manufacturer and any applicable local or national piping codes prior to specifying system pressure rating.

Application data (cont)

PIPING COMPONENTS (cont)

SYMBOL/SKETCH	DESCRIPTION	C_V FACTOR		RATING*		STEAM USE
		1/2	3/4	PSI	F	
	**BALANCE VALVE:** Variable water flow manual balancing valve with screwdriver slot adjustment screw. Application — Often used in conjunction with test port fittings for water flow balancing. Balance by temperature differential or coil pressure drop (check specifications for service fittings required if balancing by pressure drop). May be used in 3-way valve bypass line to permit equal flow balancing.	4	14	300	250	NO
	**FIXED FLOW VALVE:** Flexible orifice type (non-adjustable). Application — Used for water flow balancing. Valve automatically adjusts the flow to within 10% of set point.	Valve orifice size determines C_V factor. The orifice of these fixed flow valves changes as flow is regulated. As the water pressure increases, the orifice size decreases, thereby automatically limiting the flow rate to the specified gpm (±10%).		600	220	NO
	**STRAINER:** Y-type body with 20 mesh stainless steel screen. Application — Used for removal of small particles from system water during normal system operation. Should not be used in lieu of main system strainers. Strainer screen may have to be removed during initial high pressure system flushing during start-up. Screen should be removed and cleaned per normal maintenance schedule (provisions for strainer blow-down not provided).	9.0 Clean	19.0 Clean	400	150	N/A
	**BALL VALVE WITH MEMORY STOP:** Manual balance and shut-off valve. Application — Used for unit isolation and water flow balancing. The adjustable memory stop feature allows return to the balance point after shut-off. Check specifications for service fittings required when used for water balancing.	17	40	600	325	N/A

LEGEND

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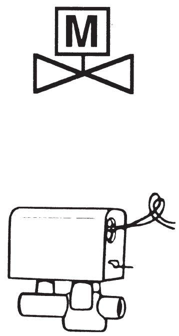
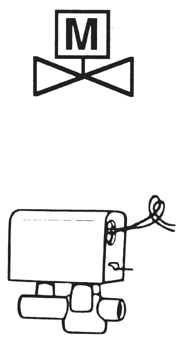
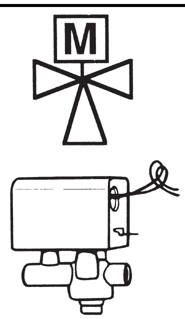
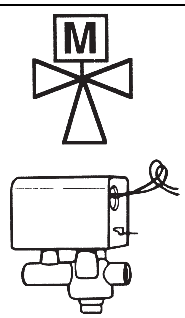
*Check all system component pressure ratings (coils, values, pumps, etc.) with manufacturer and any applicable local or national piping codes prior to specifying system pressure rating.

PIPING COMPONENTS (cont)

SYMBOL/SKETCH	DESCRIPTION	C_V FACTOR		RATING*		STEAM USE
		1/2	3/4	PSI	F	
	**2-WAY MOTORIZED VALVE (25 PSI close off differential pressure):** Electric 2-position flow control valve (open/closed). Normally closed body with manual override lever. Installed in supply line to unit. Application — All standard control and valve packages are based upon normally closed valves (valve electrically powered open and closed by spring return when electric power removed). Manual override lever allows valve to be placed in the open position for secondary (unit) flushing, constant water flow prior to start-up, etc. Manual override is automatically disengaged when valve is electrically activated. **Consult factory for normally open valve applications.**	3.5	3.5	300	200	YES 15 PSI MAX.
	**2-WAY MOTORIZED VALVE (150 PSI close off differential pressure):** Electric 2-position flow control valve (open/closed). Normally closed body with manual override lever. Installed in supply line to unit. Application — All standard control and valve packages are based upon normally closed valves (valve electrically powered open and closed by spring return when electric power removed). Manual override lever allows valve to be placed in the open position for secondary (unit) flushing, constant water flow prior to start-up, etc. Manual override is automatically disengaged when valve is electrically activated. **Consult factory for normally open valve applications.**	4.9	10.3	300	240	NO
	**3-WAY MOTORIZED VALVE (25 PSI close off differential pressure):** Electric 2-position flow control valve (closed to coil/ open to bypass or open to coil/closed to bypass). Normally closed with manual override lever. Installed in supply line to unit. Application — Same comments as 2-way motorized valve except with manual override lever engaged the valve is open to both ports and water flow will take the path of least resistance through the valve package (not necessarily 100% through the coil).	4.0	4.0	300	200	N/A
	**3-WAY MOTORIZED VALVE (150 PSI close off differential pressure):** Electric 2-position flow control valve (closed to coil/ open to bypass or open to coil/closed to bypass). Normally closed with manual override lever. Installed in supply line to unit. Application — Same comments as 2-way motorized valve except with manual override lever engaged the valve is open to both ports and water flow will take the path of least resistance through the valve package (not necessarily 100% through the coil).	4.9	4.9	300	240	N/A

LEGEND

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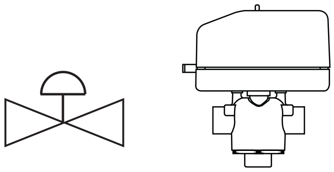
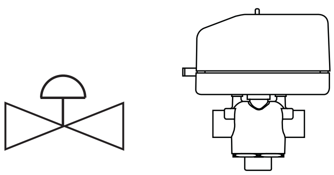
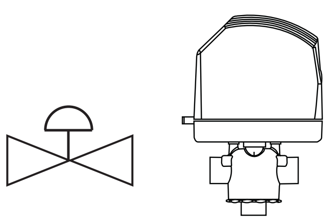
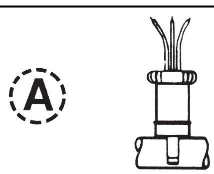
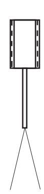
ETO — Engineering to Order

*Check all system component pressure ratings (coils, values, pumps, etc.) with manufacturer and any applicable local or national piping codes prior to specifying system pressure rating.

Application data (cont)

PIPING COMPONENTS (cont)

SYMBOL/SKETCH	DESCRIPTION	C_V FACTOR		RATING*		STEAM USE
		1/2	3/4	PSI	F	
	**MODULATING VALVE (Optional) (Non-Spring Return, Floating Point Actuator):** Modulating valves are designed to control the flow in the circuit by making incremental adjustments to the flow path within the valve. Application — To control fluid flow in fan coil units. On the 42DD,SG,SJ,SH commercial fan coil models, the factory provided modulating valve has application restrictions. In these models, the valve packages are located in the airstream, downstream of the coil. Due to the ambient temperature limitations of the modulating valves, the valves can only be used in the units listed above with 2-pipe cooling only systems.	4.0		300	200	N/A
	**MODULATING VALVE (Optional) (Non-Spring Return, Proportional Type Actuator):** Modulating valves are designed to control the flow in the circuit by making incremental adjustments to the flow path within the valve. Application — To control fluid flow in fan coil units. On the 42DD,SG,SJ,SH commercial fan coil models, the factory provided modulating valve has application restrictions. In these models, the valve packages are located in the airstream, downstream of the coil. Due to the ambient temperature limitations of the modulating valves, the valves can only be used in the units listed above with 2-pipe cooling only systems.	4.0		300	200	N/A
	**MODULATING VALVE (Requires ETO) (Spring Return):** Modulating valves are designed to control the flow in the circuit by making incremental adjustments to the flow path within the valve. Application — Same comments as non-spring return except when powered, the actuator moves to the desired position, at the same time tensing the spring return system. When power is removed for more than two minutes the spring returns the actuator to the normal position.	4.0		300	200	N/A
	**AQUASTAT:** Water temperature sensing electrical switch. (Line Voltage Controls) Application — Clips directly on nominal size 1/2 in. or 3/4 in. copper tubing for water temperature sensing. Must be correctly located for proper control operation.					
	**CHANGEOVER SENSOR:** Water temperature sensor thermistor. Application — Sensor shall clamp on the outside diameter of the pipe. Sensor plate shall bend to allow its radius to be adjusted to fit the pipe. Sensor shall be secured to the pipe with mounting clamp. Insulate the mounting location of sensor on the pipe.					

LEGEND

Cv — Coefficient of Velocity
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*Check all system component pressure ratings (coils, values, pumps, etc.) with manufacturer and any applicable local or national piping codes prior to specifying system pressure rating.

Valve packages

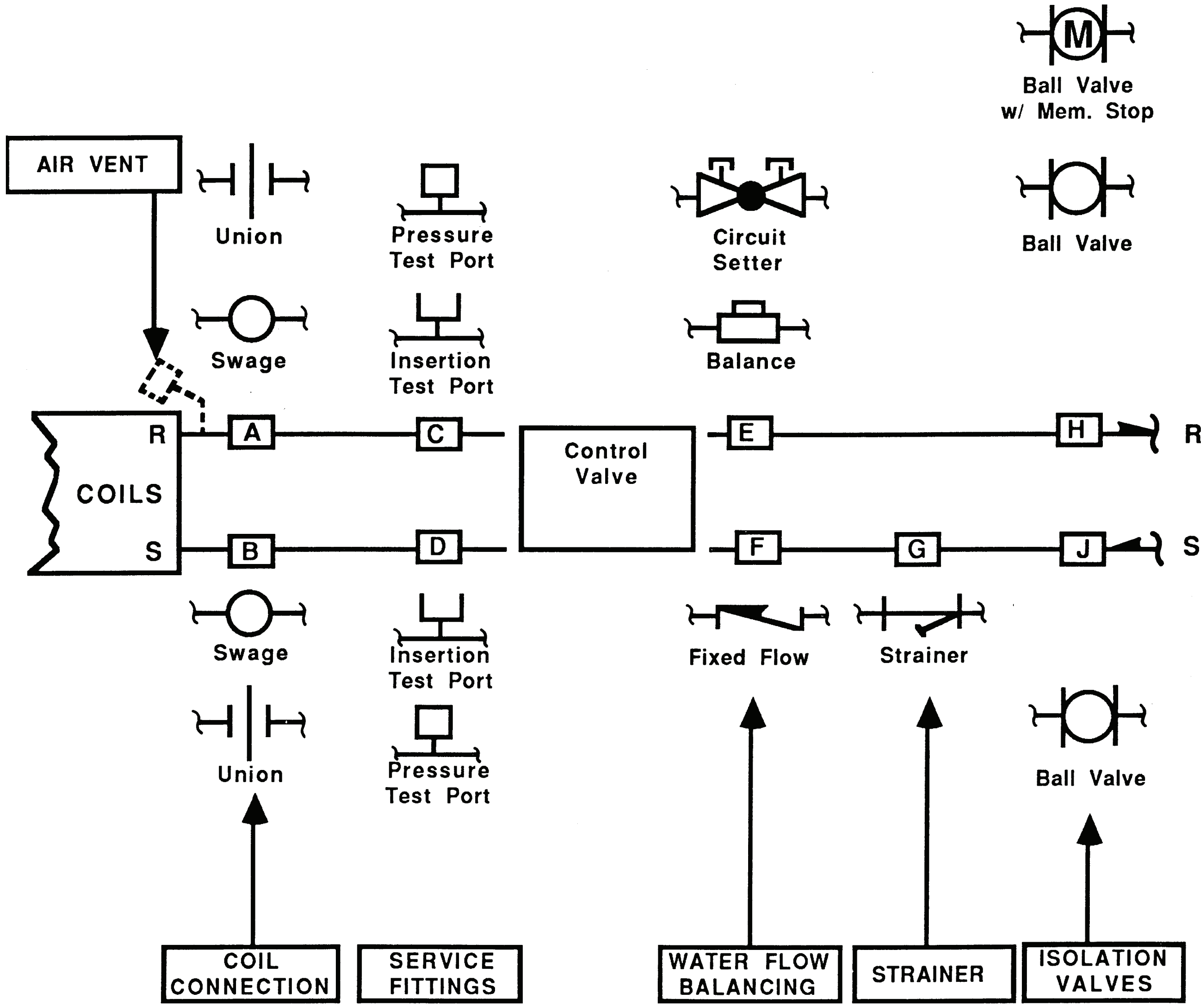
There are limitations on physical size of pneumatic valves, quantity and type of matching components, and required control interface. See Symbols and Placement of Valves diagram.

Consult factory before ordering any special valve package components that are not covered in this book.

Valve packages are shipped with the units or in unit cartons. Valve packages include belled ends for field soldering to coil connections.

All factory-furnished cooling valve packages are arranged to position as much of the package as possible over an auxiliary drain pan or drip lip. This helps minimize field piping insulation requirements.

SYMBOLS AND PLACEMENT OF VALVES



Coil Connections (Positions A & B) — When isolation valve only is added to supply or return line, the isolation valve will be factory brazed to the coil stub-out. Addition of any other component or connection to the supply or return line will change the respective coil connection(s).

Service Fittings (Positions C & D) — Optional fittings for attaching pressure/temperature sensing devices to obtain pressure drop or temperature differential across coil. Used with ball valve or balance valve where extremely accurate water flow balancing is required.

Water Flow Balancing (Positions E, F, & H) — Only one device per total valve package to be used for balancing water flow through the coil. When isolation valve (ball valve or ball valve with memory stop at position **H**) is used for water flow balancing, do not specify additional balancing device at position **E** or **F**. When balancing device is specified at position **E** or **F**, isolation valve does not require balancing feature at position **H** (with a 3-way motorized valve, a bypass balancing valve may be specified in the bypass line to permit equal flow balancing).

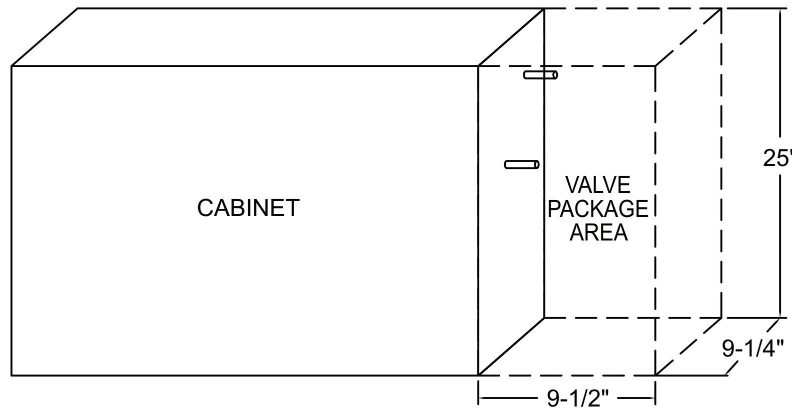
Strainer (Position G) — Does not include blow down fitting and should not be used in lieu of main piping strainers.

Isolation Valves (Positions H & J) — Normally requires one each on supply and return line (see exception under circuit setter). When position **H** is used for balancing (ball valve or ball valve with memory stop), check specifications for service valve requirements.

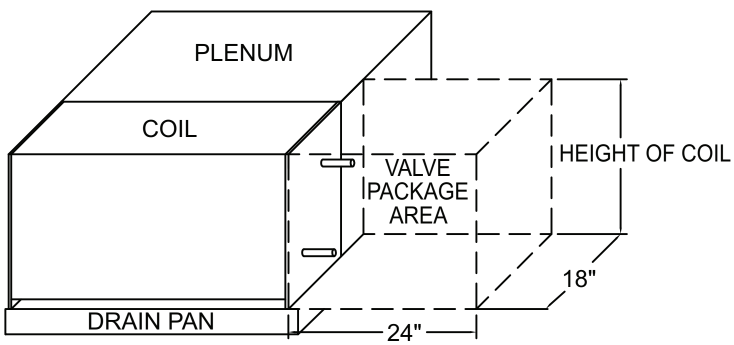
A48

Application data (cont)

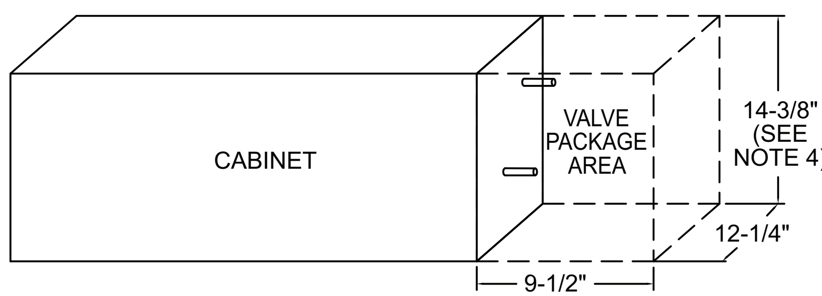
VALVE PACKAGE SPACING RECOMMENDATIONS



42VAA (SEE NOTE 3)



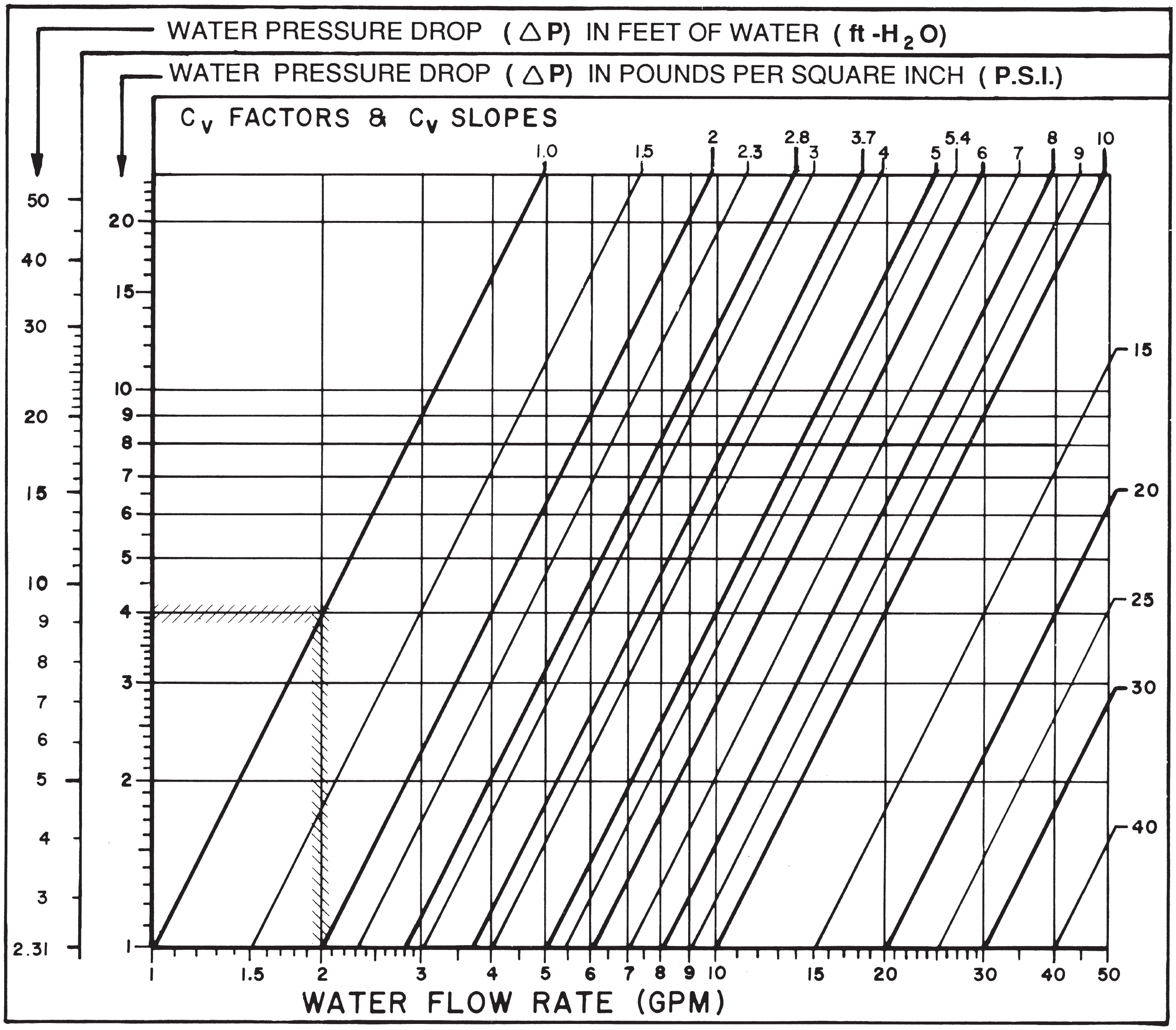
42CEA, DCA (SEE NOTES 1, 2)



42VCA (SEE NOTES 3, 4)

NOTES:
1. Valve package dimensions on ceiling models are based on a 4-pipe unit with (1) 3-way control valve, (1) ball valve, and (1) circuit setter.
2. Coil height dimensions on 42CEA and 42DCA are provided in the physical data section of the product data.
3. Valve package dimensions on floor units are based on the valve package space provided on the exposed floor models.
4. Height of the 42VCA is 16 $^{3}/_{8}$ in. depending on coil and electric heat selection.

Cv FACTOR VS WATER PRESSURE DROP



C_V FACTOR:

The flow rate in gallons per minute (gpm) through a piping component when the pressure drop (ΔP) in pounds per square inch (psi) across the component is 1.0 (psi).

Pressure drop (ft-H_2O) = 2.31 x psi (pressure drop)

GRAPH EXAMPLE:

ΔP for 2.0 gpm through a component with a C_V of 1.0 is 4.0 psi x 2.31 = 9.24 ft-H_2O

FORMULA EXAMPLE:

$$\Delta P\ (\text{ft-}H_2O) = \frac{(gpm)^2}{(C_v)^2} \times 2.31 = \frac{(2.0)^2}{(1.0)^2} \times 2.31 = 9.24\ \text{ft-}H_2O$$

TOTAL PRESSURE DROP is the **Sum** of the pressure drop of all piping and components in the water flow path.

Application data (cont)

ENTHALPY AT SATURATION

TEMPERATURE (F)	ENTHALPY AT SATURATION (Btu per lb of dry air)
40	15.230
41	15.697
42	16.172
43	16.657
44	17.149
45	17.650
46	18.161
47	18.680
48	19.211
49	19.751
50	20.301
51	20.862
52	21.436
53	22.020
54	22.615
55	23.22
56	23.84
57	24.48
58	25.12
59	25.78

TEMPERATURE (F)	ENTHALPY AT SATURATION (Btu per lb of dry air)
60	26.46
61	27.15
62	27.85
63	28.57
64	29.31
65	30.06
66	30.83
67	31.62
68	32.42
69	33.25
70	34.09
71	34.95
72	35.83
73	36.74
74	37.66
75	38.61
76	39.57
77	40.57
78	41.58
79	42.62
80	43.69

ALTITUDE COOLING CORRECTION FACTORS

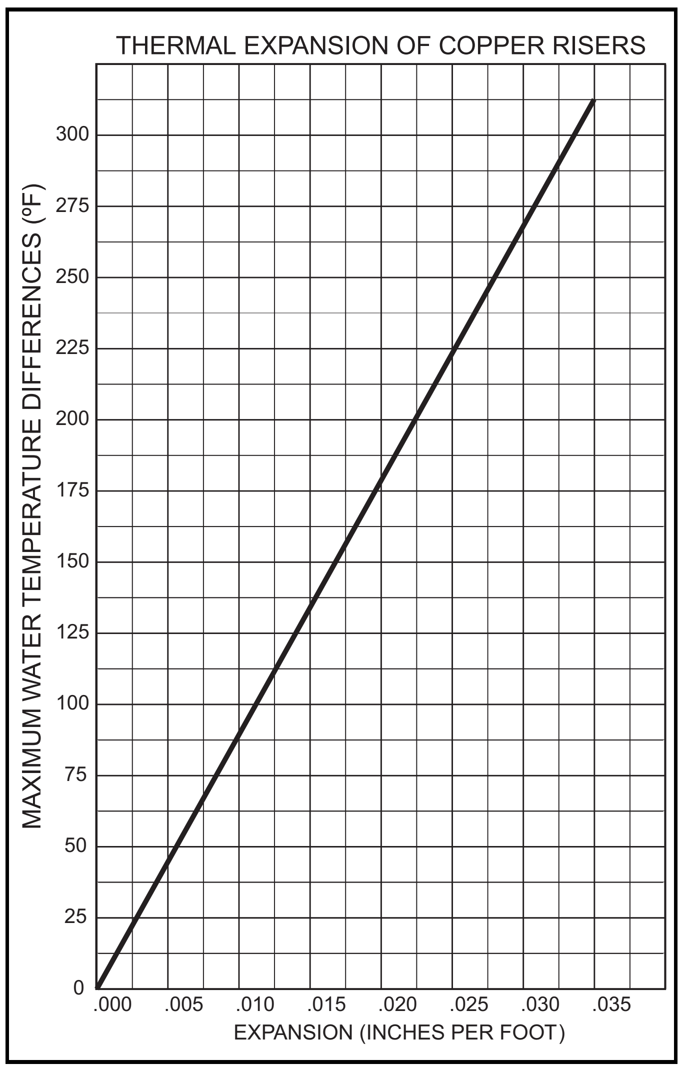
ELEVATION (ft)	TOTAL HEAT	SENSIBLE HEAT
Sea Level	1.00	1.00
1000	.990	.960
2000	.980	.930
3000	.970	.896
4000	.960	.864
5000	.940	.830
6000	.930	.800
7000	.920	.770
8000	.910	.750
9000	.900	.730

AIRFLOW CORRECTION FACTORS

CFM RATIO (Actual/Base)	TOTAL (Ct)	SENSIBLE (Cs)
1.40	1.25	1.26
1.35	1.22	1.23
1.30	1.19	1.20
1.25	1.16	1.17
1.20	1.13	1.14
1.15	1.10	1.11
1.10	1.07	1.08
1.05	1.04	1.04
1.00	1.00	1.00
0.95	0.97	0.97
0.90	0.94	0.93
0.85	0.90	0.89
0.80	0.86	0.85
0.75	0.82	0.81
0.70	0.78	0.77
0.65	0.74	0.72
0.60	0.70	0.67
0.55	0.66	0.62
0.50	0.62	0.57
0.45	0.58	0.52
0.40	0.53	0.47
0.35	0.48	0.42
0.30	0.43	0.38
0.25	0.38	0.33

LEGEND

CFM — Cubic Feet per Minute
Cs — Sensible Airflow Correction Factor
Ct — Total Airflow Correction Factor



Electric heat

Electric heaters are available for installation on Carrier fan coil units in the following applications.

Total electric heat — This system provides complete heating during the heating season; no boiler is required. Heating and cooling are now available on an individual basis throughout the year with a 2-pipe system.

Chilled water is used for cooling and the electric heater is used for heating. Individual room controls can be supplied for either manual or automatic changeover.

Auxiliary electric heat — This system is used for heating between seasons or during the cooling season when chilled water is being circulated. Individual room controls are supplied to provide electric heat only when chilled water is being circulated through the system. Water flow through the unit is shut off when the heater is turned on.

During the winter heating season, heating is provided by hot water circulated through the system. A changeover device locks out the electric heat when the hot water is circulated.

Heater construction

Strip heaters are used with Model 42C ceiling units, Model 42D ducted units, Model 42S stack units and Model 42V (except 42VCA and VEA).

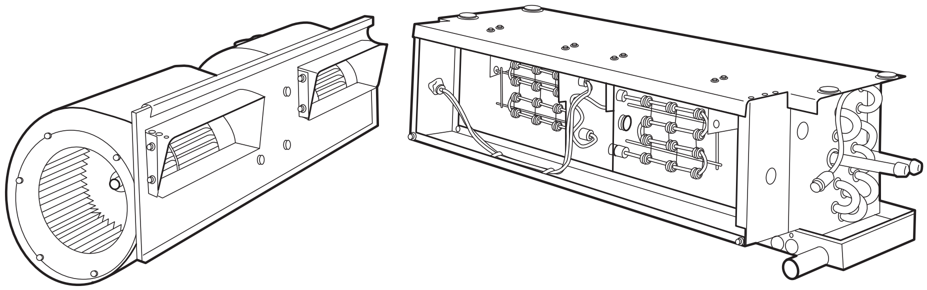
These heaters consist of coils of high grade resistance wire, insulated by ceramic insulators on plated steel brackets. High limit thermal cutouts protect the unit in the event of airflow loss.

All heaters except those used in 42S stack units are positioned on the incoming (preheat) side of the unit coil. On 42S stack units, the strip heater is located in the fan discharge on the leaving side of the coil.

Sheath heaters are used with Model 42VCA and 42VEA vertical units. There heaters consist of high grade resistance wire, centered in a $^1/_2$ in. diameter copper plated steel sheath. The wire is insulated from the sheath by magnesium oxide powder packed around it. To increase the heater surface exposed to air, a 1 $^1/_4$ in. OD fin of copper plated steel is wound around the sheath in a spiral that makes 5 turns per linear inch. Sheath and fin are permanently bound together by copper brazing. The heaters are positioned on the leaving (rehead) side of the unit coil.

Heater electrical data

1. Load voltage may be 120, 208, 240 or 277 volts. For unit size and kW limitations, refer to the specific unit catalogs.
2. All heaters are single stage and single phase except for 42SM, which offers 2-stage electric heaters.
3. Unless a single power-source option is selected, the electric heat units require 2 separate power sources. With the single power-source option, only one line circuit need be brought into the unit. Fuse protection is added to the motor/control circuit to protect these components. This is separate from the field-furnished total unit overcurrent protection.



MODEL 42C CEILING UNIT WITH ELECTRIC STRIP HEATER

Application data (cont)

HEATER ELECTRICAL DATA

42C SERIES

HEATER VOLTAGE	kW	CAPACITY (Btuh)	UNIT SIZE						
			02	03	04	06	08	10	12
120	0.5	1,708	*	*					
	1.0	3,415	*	*	*	*	*		
	1.5	5,123	*	*	*	*	*		
	2.0	6,830	*	*	*	*	*	*	*
	3.0	10,245		*	*	*	*	*	*
208	0.5	1,708	*	*					
	1.0	3,415	*	*	*	*	*		
	1.5	5,123	*	*	*	*	*		
	2.0	6,830	*	*	*	*	*	*	*
	3.0	10,245		*	*	*	*	*	*
	4.0	13,660				*	*	*	*
	5.0	17,075				*	*	*	*
	6.0	20,490				*	*	*	*
	8.0	27,320						*	*
240,277	0.5	1,708	*	*					
	1.0	3,415	*	*	*	*	*		
	1.5	5,123	*	*	*	*	*		
	2.0	6,830	*	*	*	*	*	*	*
	3.0	10,245		*	*	*	*	*	*
	4.0	13,660				*	*	*	*
	5.0	17,075				*	*	*	*
	6.0	20,490				*	*	*	*
	8.0	27,320						*	*
	10.0	34,150							*

42V SERIES

HEATER VOLTAGE	kW	CAPACITY (Btuh)	UNIT SIZE							
			02	03	04	05	06	08	10	12
120	1.0	3,415	*	*	*	*	*			
	1.5	5,123		*	*	*	*			
	2.0	6,830			*	*	*	*		
	3.0	10,245				*	*	*	*	*
208, 240	1.0	3,415	*	*	*	*	*			
	1.5	5,123		*	*	*	*			
	2.0	6,830			*	*	*	*		
	3.0	10,245				*	*	*	*	*
	4.0	13,660						*	*	*
277	1.0	3,415	*	*	*	*	*			
	1.5	5,123		*	*	*	*			
	2.0	6,830			*	*	*	*		
	3.0	10,245				*	*	*	*	*
	4.0	13,660						*	*	*
	5.0	17,075							*	*
	6.0	20,490								*

NOTE: All heaters are single-stage and single-phase. Contact your Carrier representative for heater availability for 220-1-50 units.

42D SERIES

HEATER VOLTAGE	kW	CAPACITY (Btuh)	UNIT SIZE							
			06	08	10	12	14	16	18	20
120	2.0	6,830	*	*	*					
	3.0	10,245	*	*	*					
208, 240, 277	2.0	6,830	*	*	*					
	3.0	10,245	*	*	*					
	4.0	13,660	*	*	*	*	*	*	*	*
	5.0	17,075		*	*	*	*	*	*	*
	6.0	20,490		*	*	*	*	*	*	*
	7.0	23,905			*	*	*	*	*	*
	8.0	27,320				*	*	*	*	*
	9.0	30,735				*	*	*	*	*
	10.0	34,150					*	*	*	*
	12.0	40,980						*	*	*
	14.0	47,810								*

NOTE: All heaters are single-stage and single-phase.

42S SERIES

HEATER VOLTAGE	kW	UNIT SIZE								
		03	04	06	08	10	12	14	16	20
120	1.0	*	*	*	*	*	*			
	1.5	*	*	*	*	*	*			
	2.0	*	*	*	*	*	*			
	3.0	*	*	*	*	*	*			
208	1.0	*	*	*	*	*	*			
	1.5	*	*	*	*	*	*			
	2.0	*	*	*	*	*	*			
	3.0	*	*	*	*	*	*			
	4.0		*	*	*	*	*	*	*	*
	5.0			*	*	*	*			
	6.0			*	*	*	*	*	*	*
	8.0				*	*	*	*	*	*
240	1.0	*	*	*	*	*	*			
	1.5	*	*	*	*	*	*			
	2.0	*	*	*	*	*	*			
	3.0	*	*	*	*	*	*			
	4.0		*	*	*	*	*	*	*	*
	5.0			*	*	*	*			
	6.0			*	*	*	*	*	*	*
	8.0				*	*	*	*	*	*
	10.0					*	*	*	*	*
277	1.0	*	*	*	*	*	*			
	1.5	*	*	*	*	*	*			
	2.0	*	*	*	*	*	*			
	3.0	*	*	*	*	*	*			
	4.0		*	*	*	*	*	*	*	*
	5.0			*	*	*	*			
	6.0			*	*	*	*	*	*	*
	8.0				*	*	*	*	*	*
	10.0					*	*	*	*	*
	12.0							*	*	*

NOTES:
1. Contact your Carrier representative for heater availability on 42SU unit quick ship program.
2. 12 kW heater only available with 277V heater voltage.

ECM motor control methods

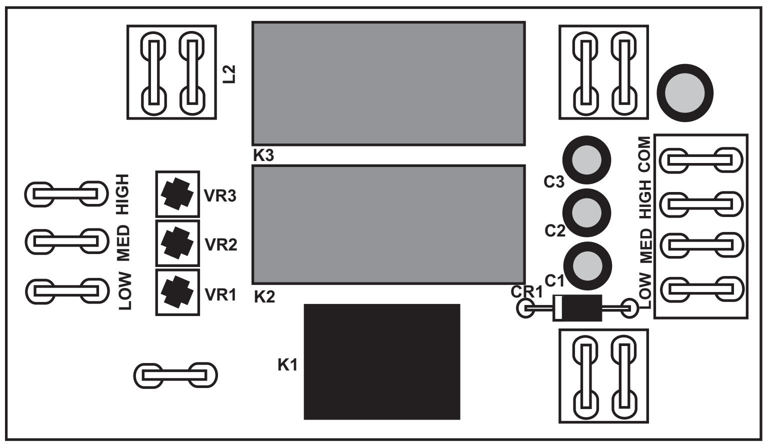
There are three main control methods to control the speed of electronically commutated motor (ECM) for desirable airflow for a given application.

3-discrete speed input, potentiometer field speed adjustment — This method uses the ECM with potentiometer field adjustment. The relay board will have three main circuits for HI, MEDIUM, and LOW speed. Each of these speeds can be adjusted by potentiometer to any value in the motor's operating range. This will allow the customization of air flow on each speed of the fan coil unit to better suit any requirements.

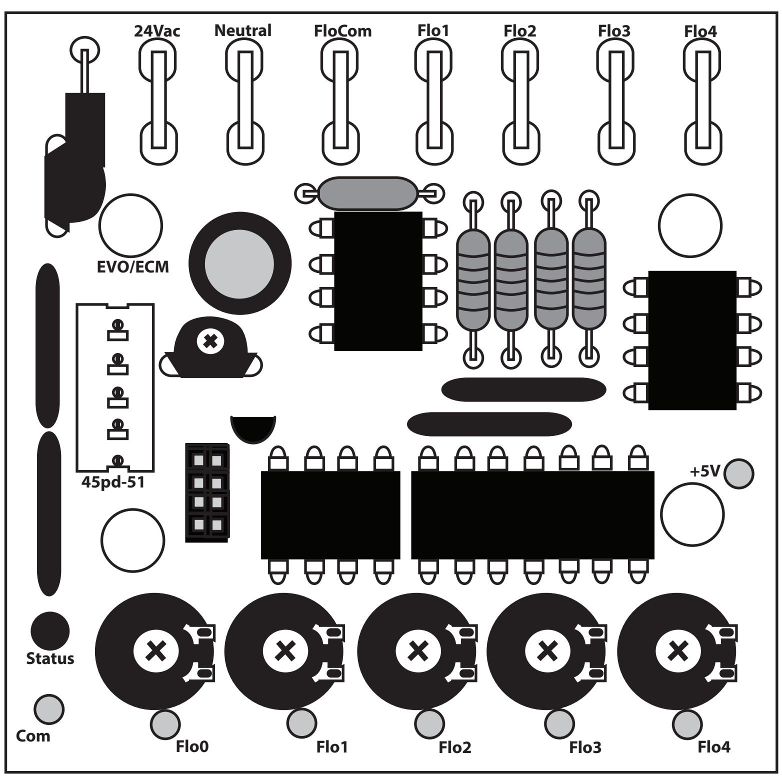
4-discrete speed input, potentiometer field speed adjustment, solid state (only with 24-v controls by other option) — This is the same as 3-discrete speed input but with additional fourth speed. All 4 speeds can be adjusted by potentiometer to any value in the motor's operating range.

Control method no. 3 — ECM variable speed (only with 24-v controls by other option) — This method requires 0 to 10-v signal for fan speed. It has no predetermined fan speeds and will ramp the motor fan speed according to the controller used on the fan coil unit. All ECM motor packages use a constant torque operating mode. An ETO request is required for pricing and availability of constant airflow operation.

3-DISCRETE SPEED INPUT



4-DISCRETE SPEED INPUT



Model number nomenclature

42 CA A 03 A L C Y 6 Y Y Y Y

42 – Series Fan-Coil Unit

Product Type
CA – Furred-In
CE – Furred-In with Plenum
CG – Cabinet
CK – Telescoping Bottom Panel

Design Series (A or B*)

Unit Size – Airflow (cfm)
02 – 200
03 – 300
04 – 400
06 – 600
08 – 800
10 – 1000
12 – 1200

Coil Options
A – 3 Row (Standard)
B – 4 Row High Capacity
C – 3/1 Opposite End Connection
D – 3/1 Same End Connection
E – 3/2 Opposite End Connection
F – 3/2 Same End Connection
G – 4/1 Opposite End Connection
H – 4/1 Same End Connection

Hand
R – Right
L – Left

* Model 42CG only.
† Contact Application Engineering for data on the 50 Hz motor.

Thermostat Packages

Unit Control Options for 24V Controls

Valve Packages

Filter

Airflow Configuration
5 – Bottom Return, Front Supply
6 – Rear Return, Front Supply
8 – Bottom Return, Bottom Supply

Electric Heaters
Y – None
A-Z, 1-9 – 42C

Motor Options
1 – 115-v High-Static Permanent Split Capacitor (HSPSC)
2 – 208/1/60 HSPSC
3 – 230/1/60 HSPSC
4 – 277/1/60 HSPSC
A – 115-v Electonically Commutated Motor (ECM) with Control Option 1
B – 115-v ECM with Control Option 2
C – 115-v Permanent Split Capacitor (PSC) (Standard)
D – 208/1/60 PSC
E – 230/1/60 PSC
F – 277/1/60 PSC
G – 115-v ECM with Control Option 3
H – 208-v ECM with Control Option 1
J – 208-v ECM with Control Option 2
K – 208-v ECM with Control Option 3
L – 230-v ECM with Control Option 1
M – 230-v ECM with Control Option 2
N – 230-v ECM with Control Option 3
P – 277-v ECM with Control Option 1
Q – 277-v ECM with Control Option 3
R – 277-v ECM with Control Option 2
V – 220/1/50 PSC†

Control Option 1 – 3-Discrete Potentiometer Field Speed Adjustment
Control Option 2 – Variable Flow 0-10 VDC or 4-20 mA
Control Option 3 – 4-Discrete Potentiometer Field Speed Adjustment

AHRI capacity ratings

The 42C Series fan coil units are certified in compliance with the Air-Conditioning, Heating and Refrigeration Institute (AHRI) Industry Standard 440 for room fan coil units. Approved standard ratings are tabulated below.

AHRI CERTIFIED™
www.ahridirectory.org
Room Fan-Coils
AHRI Standard 440

AHRI APPROVED STANDARD RATINGS*

UNIT	UNIT SIZE	COIL ROWS	NOMINAL CFM	COOLING CAPACITY		POWER INPUT (WATTS)†
				Total MBtuh	Sensible MBtuh	
42CA,CE,CG,CK	02	3	200	6.0	4.4	87
	03		300	9.0	6.3	85
	04		400	12.1	8.8	165
	06		600	17.3	13.0	225
	08		800	22.6	16.2	235
	10		1000	27.5	21.0	305
	12		1200	32.8	25.0	435
	02	4	200	6.9	4.3	87
	03		300	9.8	6.5	85
	04		400	13.8	9.8	145
	06		600	19.6	14.3	220
	08		800	25.5	18.8	235
	10		1000	31.0	22.0	300
	12		1200	37.2	27.7	425

LEGEND

MBtuh — Capacity (Btuh in thousands)

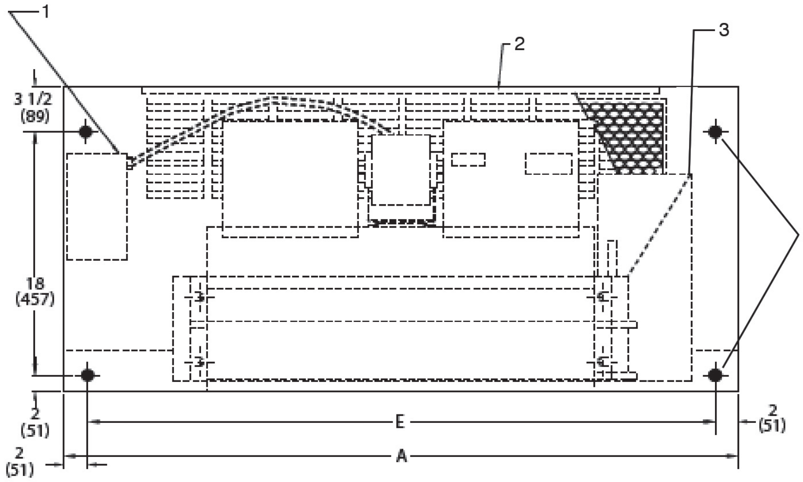
*Ratings based on motor at high fan speed, standard air and dry coil operation, 10° F water temperature rise; entering-air temperature 67 F wb; 80 F db; entering water temperature 45 F.
†Motor type permanent split capacitor operating at 115-1-60 voltage.

Physical data

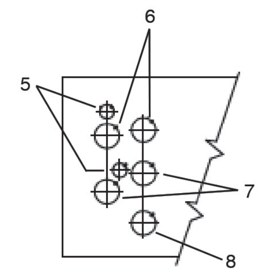
UNIT SIZE 42C	02	03	04	06	08	10	12
NOMINAL AIRFLOW (cfm)	200	300	400	600	800	1000	1200
SHIPPING WEIGHT (lb)*							
42CA	36	39	49	59	64	95	107
42CE	55	60	70	82	95	135	154
42CG	98	118	126	168	176	215	245
42CK	115	120	135	150	155	227	241
COIL WATER WEIGHT (Approx lb per row of coil)							
42CA, CE, CG, CK	0.7	0.8	1.0	1.4	1.7	2.3	2.7
COILS							
FPI	10 fins/inch						
Coil Face Area (sq ft)	0.8	1.1	1.4	1.9	2.3	3.2	3.7
MOTOR (qty)							
42C Series	1	1	1	1	1	2	2
BLOWER (qty)							
42CA, CE, CG, CK	1	1	2	2	2	4	4
FILTERS Nominal Size (in.) (1-in. thick)							
42CA	NA	NA	NA	NA	NA	NA	NA
42CE†	10 x 18	10 x 22	10 x 28	10 x 33	10 x 40	10 x 54	10 x 62
42CG							
Bottom Return	10 x 23$^1/_2$	10 x 28	10 x 32$^1/_2$	10 x 37	10 x 41	10 x 54$^1/_2$	10 x 63
Rear Return	8 x 23$^1/_2$	8 x 28	8 x 32$^1/_2$	8 x 37	8 x 41	8 x 54$^1/_2$	8 x 63
42CK							
Bottom Return	10 x 28	10 x 28	10 x 33	10 x 45	10 x 45	10 x 62	10 x 62
Rear Return	7 x 21	7 x 21	7 x 27	7 x 38	7 x 38	7 x 52	7 x 52
Qty	1	1	1	1	1	1	1
SUPPLY DUCT COLLAR	1-in.						
PIPING CONNECTIONS (Sweat) (in.)							
Drain Connection	$^7/_8$ OD						
Tell-Tale Drain	$^5/_8$ OD						

*Calculate operating weight of unit: shipping weight + coil water weight x number of coil rows. Electric heating coils add 2 lb.
†Filter size if located in return-air plenum.

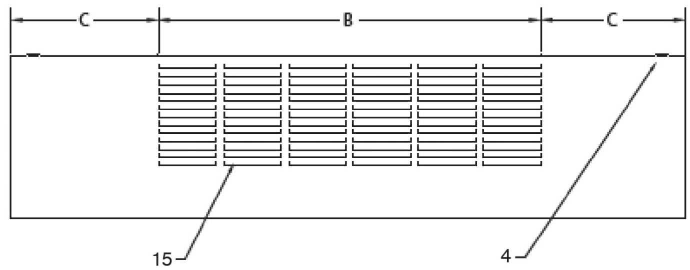
42CG HORIZONTAL CABINET UNIT



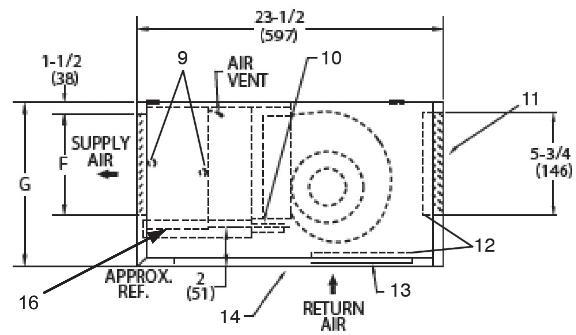
TOP VIEW



PARTIAL REAR VIEW
(TYPICAL BOTH SIDES)



FRONT VIEW



RIGHT SIDE VIEW

LEGEND

1 — Junction Box, 4 in. x 4 in.
2 — Optional Return Air Location
3 — Optional Drip Lip, shipped loose
4 — Mounting Holes (4), Rubber Grommets have $^{3}/_{8}$-in. Diameter Hole
5 — Electrical Knockout, $^{7}/_{8}$-in. Diameter
6 — Return Knockout, 1-in. Diameter
7 — Supply Knockout, $1^{1}/_{2}$-in. Diameter
8 — Drain Knockout, $1^{1}/_{2}$-in. Diameter
9 — Supply, Return Connections
10 — Drain Connection, $^{7}/_{8}$-in. OD
11 — Optional Valve Package (inside cabinet)
12 — Filter
13 — Standard Stamped-Return Air Grille
14 — Removeable Hinged Access Panel
15 — Supply Grille, Stamped, Standard
16 — Drain Pan

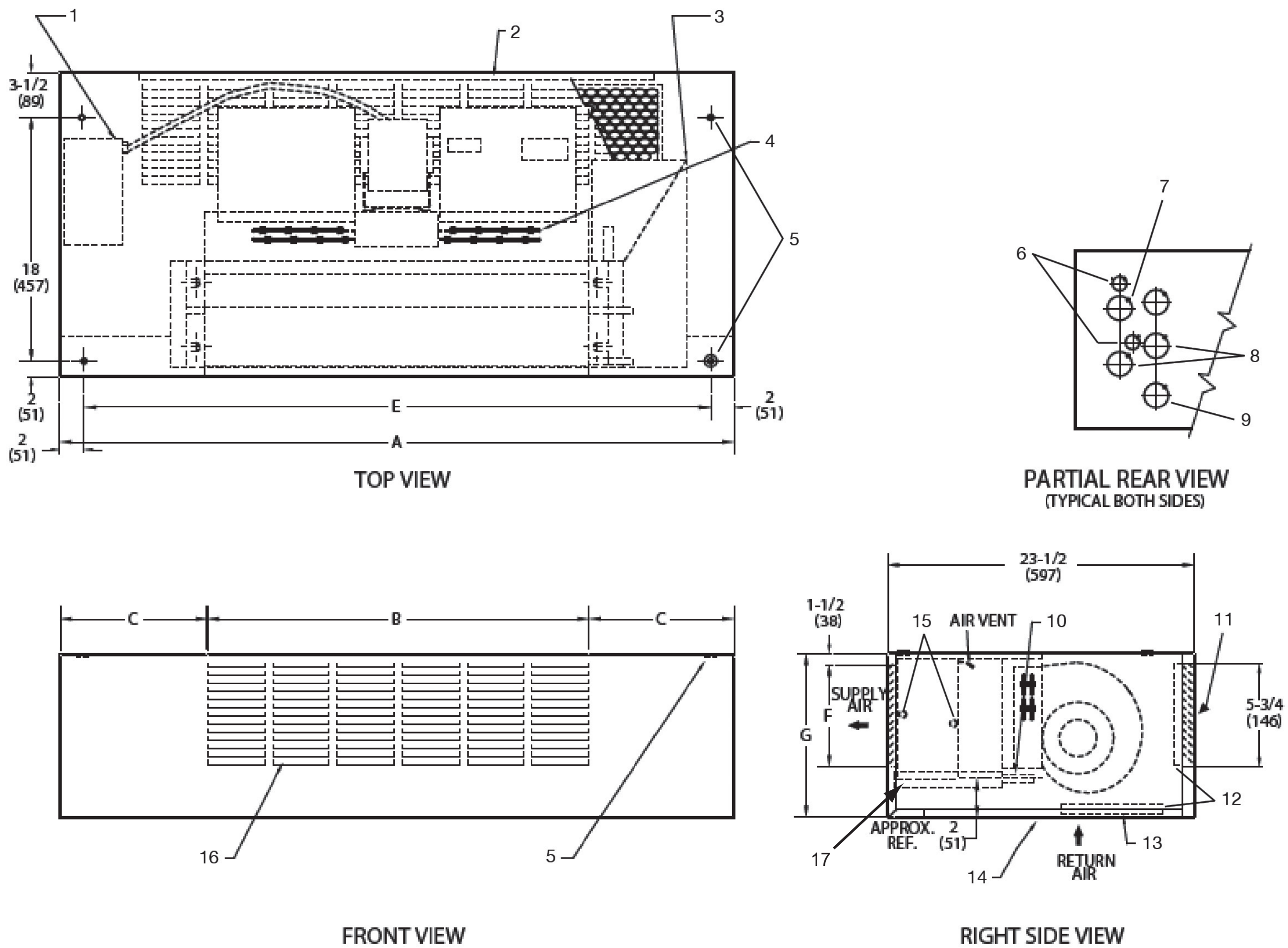
NOTES:
1. Right hand unit shown; left hand unit opposite. Coil connection locations are $\pm^{5}/_{8}$-inches.
2. Unit sizes 02 and 03 have one motor, one blower; sizes 04 through 08 have one motor, 2 blowers; sizes 10 and 12 have 2 motors, 4 blowers.
3. Cabinet has an Arctic White baked finish.
4. Refer to supply and return connections above for coil stub-out locations.
5. Not shown: optional drip lip, 3-speed fan switch; wall plate, $^{1}/_{2}$-in. fiberglass insulation on inside of casing, closed cell foam on main drain pan.
6. See 42CA-203-1 for optional coil connections.
7. Valve package is factory-installed inside the cabinet when ordered with the unit (based on component size).
8. Dimensions shown in inches (mm).

UNIT SIZE	NOM AIRFLOW (Cfm)	DIMENSIONS (in.)						QTY/UNIT		FACE AREA (sq ft)	UNIT WEIGHT* (lb)
		A	B	C	E	F	G	Blower	Motor		
02	200	38	$17^{1}/_{8}$	$10^{7}/_{16}$	34	$5^{3}/_{4}$	11	1	1	0.83	98
03	300	42	$21^{1}/_{2}$	$10^{1}/_{4}$	38	$5^{3}/_{4}$	11	1	1	1.08	118
04	400	48	$25^{7}/_{8}$	$11^{1}/_{16}$	44	$5^{3}/_{4}$	11	2	1	1.35	126
06	600	53	$34^{5}/_{8}$	$9^{3}/_{16}$	49	$6^{3}/_{4}$	12	2	1	1.88	168
08	800	60	39	$10^{1}/_{2}$	56	$6^{3}/_{4}$	12	2	1	2.31	176
10	1000	74	$52^{1}/_{8}$	$10^{15}/_{16}$	70	$6^{3}/_{4}$	12	4	2	3.16	215
12	1200	82	$60^{7}/_{8}$	$10^{9}/_{16}$	78	$6^{3}/_{4}$	12	4	2	3.65	245

*Unit weights are based on dry coils and minimum rows. Weights exclude packaging, valves, and other components.

Base unit dimensions (cont)

42CG HORIZONTAL CABINET WITH ELECTRIC HEAT



LEGEND

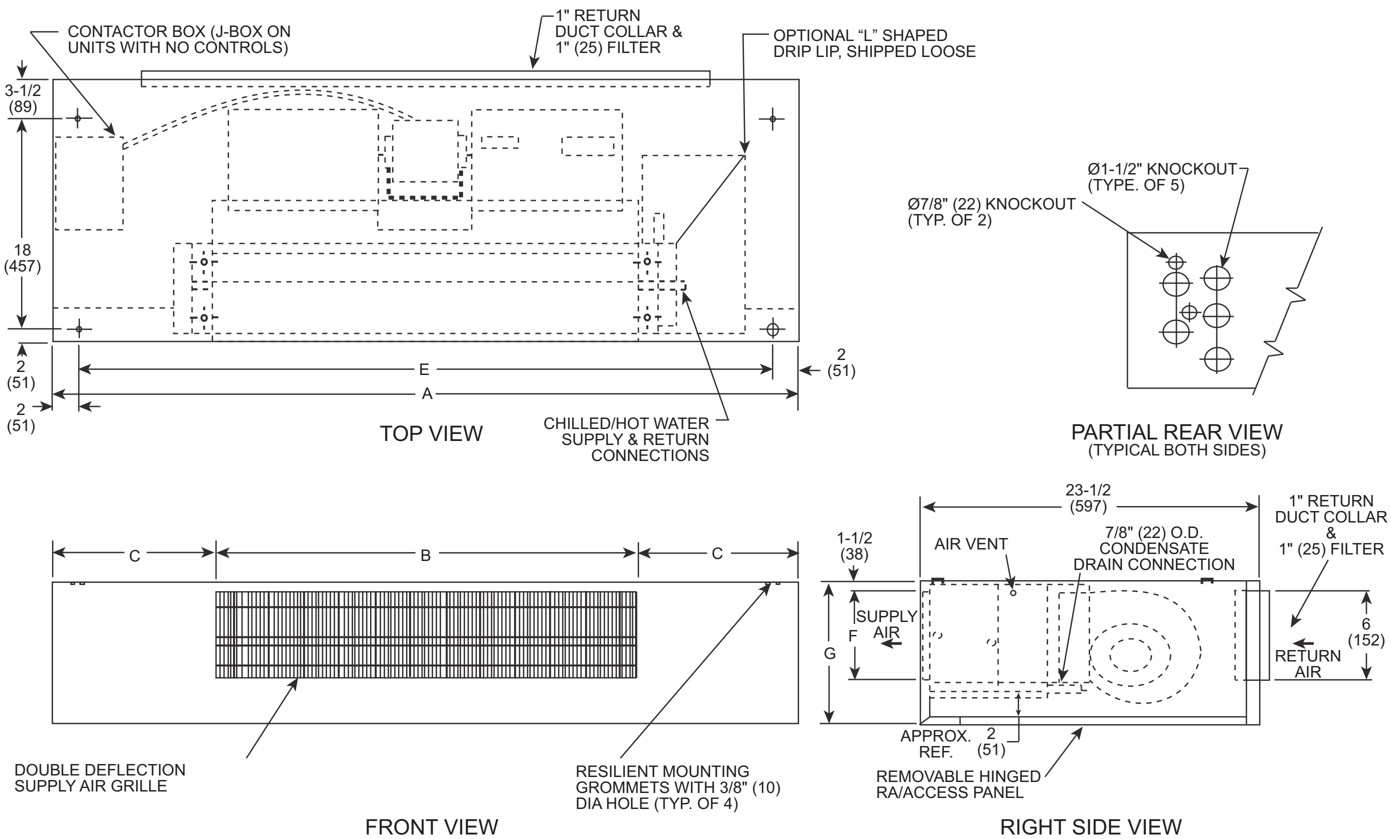
1 — Junction Box, 4 in. x 4 in.
2 — Optional Stamped Rear Return Grille
3 — Optional Drip Lip, shipped loose
4 — Electric Strip Heater Element
5 — Mounting Holes (4), Rubber Grommets have 3/8-in. Diameter Hole
6 — Electrical Knockout, 7/8-in. Diameter
7 — Return Knockout, 1-in. Diameter
8 — Supply Knockout, 1 1/2-in. Diameter
9 — Drain Knockout, 1 1/2-in. Diameter
10 — Drain Connection, 7/8-in. OD
11 — Optional Valve Package (inside cabinet)
12 — Filter
13 — Standard Stamped-Return Air Grille
14 — Removeable Hinged Access Panel
15 — Supply, Return Connections
16 — Supply Grille, Stamped, Standard
17 — Drain Pan

NOTES:
1. Right hand unit shown; left hand unit opposite. Coil connection locations are ±5/8-inches.
2. Unit sizes 02 and 03 have one motor, one blower; sizes 04 through 08 have one motor, 2 blowers; sizes 10 and 12 have 2 motors, 4 blowers.
3. Cabinet has an Arctic White baked finish.
4. Refer to supply and return connections above for coil stub-out locations.
5. Not shown: optional drip lip, 3-speed fan switch; wall plate, 1/2-in. fiberglass insulation on inside of casing, closed cell foam on main drain pan.
6. See 42CA-203-1 for optional coil connections.
7. Valve package is factory-installed inside the cabinet when ordered with the unit (based on component size).
8. Dimensions shown in inches (mm).

UNIT SIZE	NOM AIRFLOW (Cfm)	DIMENSIONS (in.)						QTY/UNIT		FACE AREA (sq ft)	UNIT WEIGHT* (lb)
		A	B	C	E	F	G	Blower	Motor		
02	200	38	17 1/8	10 7/16	34	5 3/4	11	1	1	0.83	98
03	300	42	21 1/2	10 1/4	38	5 3/4	11	1	1	1.08	118
04	400	48	25 7/8	11 1/16	44	5 3/4	11	2	1	1.35	126
06	600	53	34 5/8	9 3/16	49	6 3/4	12	2	1	1.88	168
08	800	60	39	10 1/2	56	6 3/4	12	2	1	2.31	176
10	1000	74	52 1/8	10 15/16	70	6 3/4	12	4	2	3.16	215
12	1200	82	60 7/8	10 9/16	78	6 3/4	12	4	2	3.65	245

*Unit weights are based on dry coils and minimum rows. Weights exclude packaging, valves, and other components.

42CG HORIZONTAL CABINET WITH DOUBLE DEFLECTOR SUPPLY AIR GRILLE AND DUCT REAR RETURN

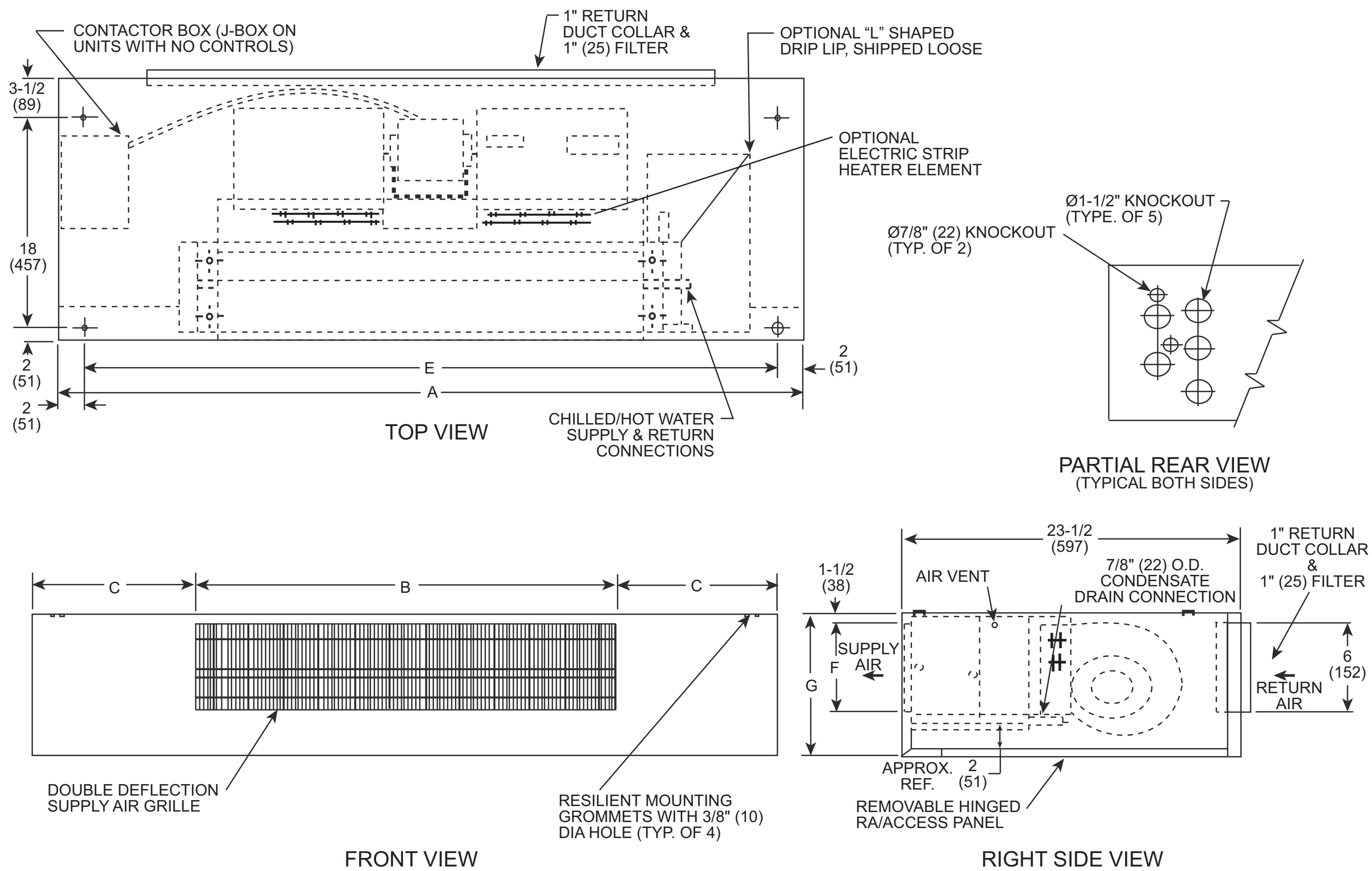


NOTES:
1. Right hand unit shown; left hand unit opposite.
2. Internal factory valve package and drains may not align with cabinet knockouts.
3. All dimensions ± $^{1}/_{4}$-in.
4. Cabinet is Arctic White polyester powder coat paint.

UNIT SIZE	NOM AIRFLOW (Cfm)	DIMENSIONS (in.)						DUCTED REAR RETURN SIZE (in.)	FILTER SIZE (in.)	QTY/UNIT	
		A	B	C	E	F	G			Blower	Motor
02	200	38	$17^{1}/_{8}$	$10^{7}/_{16}$	34	$5^{3}/_{4}$	11	6 x $21^{1}/_{2}$	8 x $23^{1}/_{2}$	1	1
03	300	42	$21^{1}/_{2}$	$10^{1}/_{4}$	38	$5^{3}/_{4}$	11	6 x $25^{3}/_{4}$	8 x 28	1	1
04	400	48	$25^{7}/_{8}$	$11^{1}/_{16}$	44	$5^{3}/_{4}$	11	6 x $30^{1}/_{4}$	8 x $32^{1}/_{2}$	2	1
06	600	53	$34^{5}/_{8}$	$9^{3}/_{16}$	49	$6^{3}/_{4}$	12	6 x $34^{1}/_{2}$	8 x 37	2	1
08	800	60	39	$10^{1}/_{2}$	56	$6^{3}/_{4}$	12	6 x 39	8 x 41	2	1
10	1000	74	$52^{1}/_{8}$	$10^{15}/_{16}$	70	$6^{3}/_{4}$	12	6 x 52	8 x $54^{1}/_{2}$	4	2
12	1200	82	$60^{7}/_{8}$	$10^{9}/_{16}$	78	$6^{3}/_{4}$	12	6 x $60^{3}/_{4}$	8 x 63	4	2

Base unit dimensions (cont)

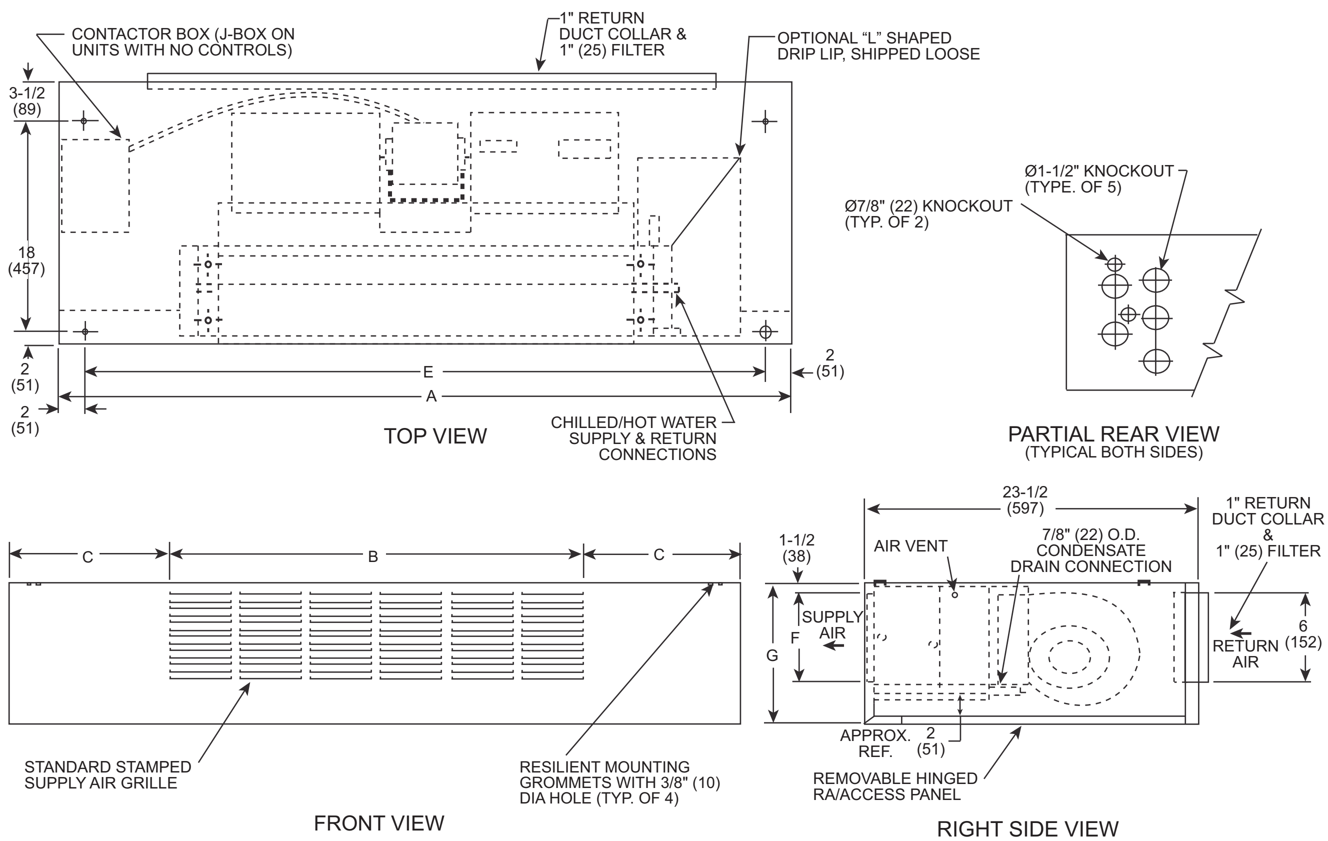
42CG HORIZONTAL CABINET WITH DOUBLE DEFLECTOR SUPPLY AIR GRILLE, DUCT REAR RETURN AND HEATER



NOTES:
1. Right hand unit shown; left hand unit opposite.
2. Internal factory valve package and drains may not align with cabinet knockouts.
3. All dimensions ± $^{1}/_{4}$-in.
4. Cabinet is Arctic White polyester powder coat paint.

UNIT SIZE	NOM AIRFLOW (Cfm)	DIMENSIONS (in.)						DUCTED REAR RETURN SIZE (in.)	FILTER SIZE (in.)	QTY/UNIT	
		A	B	C	E	F	G			Blower	Motor
02	200	38	17$^{1}/_{8}$	10$^{7}/_{16}$	34	5$^{3}/_{4}$	11	6 x 21$^{1}/_{2}$	8 x 23$^{1}/_{2}$	1	1
03	300	42	21$^{1}/_{2}$	10$^{1}/_{4}$	38	5$^{3}/_{4}$	11	6 x 25$^{3}/_{4}$	8 x 28	1	1
04	400	48	25$^{7}/_{8}$	11$^{1}/_{16}$	44	5$^{3}/_{4}$	11	6 x 30$^{1}/_{4}$	8 x 32$^{1}/_{2}$	2	1
06	600	53	34$^{5}/_{8}$	9$^{3}/_{16}$	49	6$^{3}/_{4}$	12	6 x 34$^{1}/_{2}$	8 x 37	2	1
08	800	60	39	10$^{1}/_{2}$	56	6$^{3}/_{4}$	12	6 x 39	8 x 41	2	1
10	1000	74	52$^{1}/_{8}$	10$^{15}/_{16}$	70	6$^{3}/_{4}$	12	6 x 52	8 x 54$^{1}/_{2}$	4	2
12	1200	82	60$^{7}/_{8}$	10$^{9}/_{16}$	78	6$^{3}/_{4}$	12	6 x 60$^{3}/_{4}$	8 x 63	4	2

42CG HORIZONTAL CABINET WITH STAMPED SUPPLY AIR GRILLE AND DUCT REAR RETURN

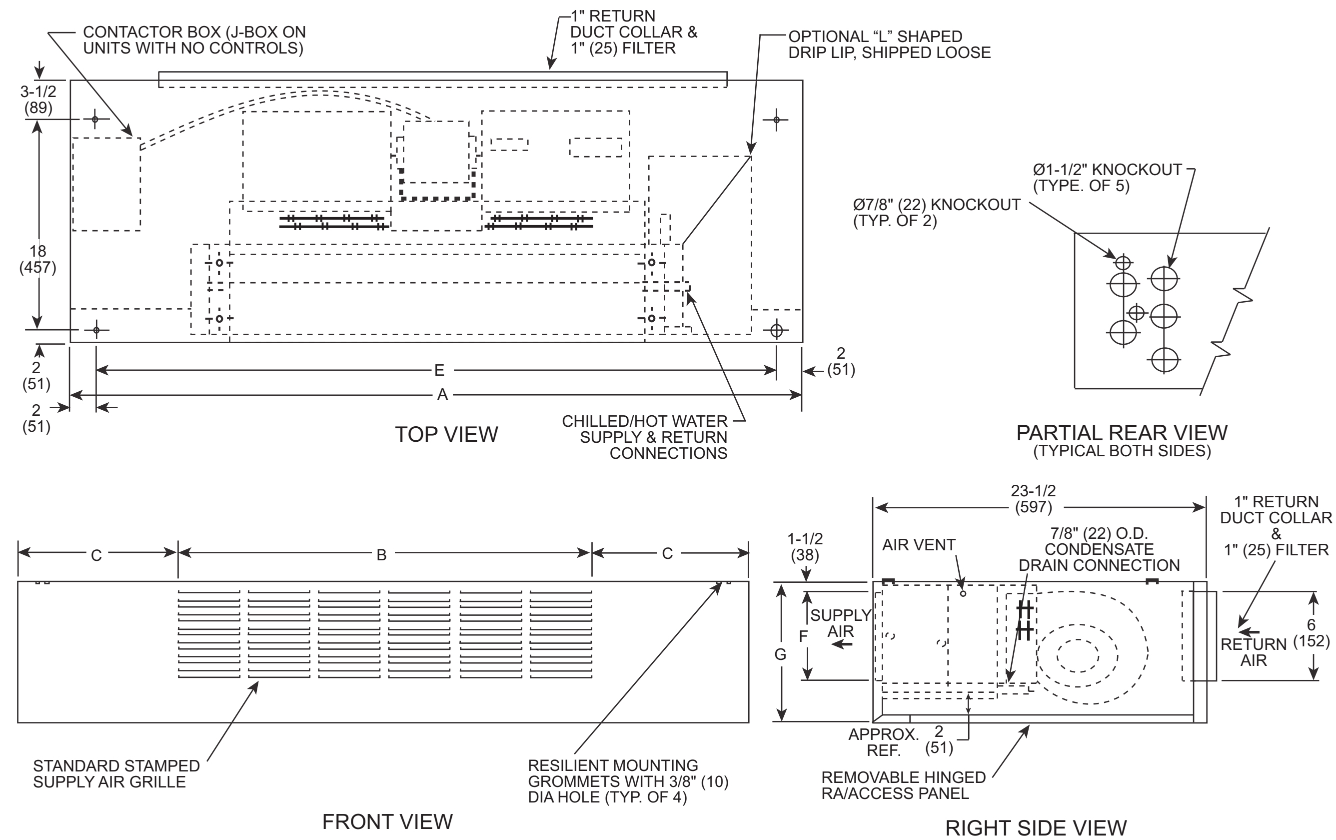


NOTES:
1. Right hand unit shown; left hand unit opposite.
2. Internal factory valve package and drains may not align with cabinet knockouts.
3. All dimensions ± $^1/_4$-in.
4. Cabinet is Arctic White polyester powder coat paint.

UNIT SIZE	NOM AIRFLOW (Cfm)	DIMENSIONS (in.)						DUCTED REAR RETURN SIZE (in.)	FILTER SIZE (in.)	QTY/UNIT	
		A	B	C	E	F	G			Blower	Motor
02	200	38	$17^1/_8$	$10^7/_{16}$	34	$5^3/_4$	11	6 x $21^1/_2$	8 x $23^1/_2$	1	1
03	300	42	$21^1/_2$	$10^1/_4$	38	$5^3/_4$	11	6 x $25^3/_4$	8 x 28	1	1
04	400	48	$25^7/_8$	$11^1/_{16}$	44	$5^3/_4$	11	6 x $30^1/_4$	8 x $32^1/_2$	2	1
06	600	53	$34^5/_8$	$9^3/_{16}$	49	$6^3/_4$	12	6 x $34^1/_2$	8 x 37	2	1
08	800	60	39	$10^1/_2$	56	$6^3/_4$	12	6 x 39	8 x 41	2	1
10	1000	74	$52^1/_8$	$10^{15}/_{16}$	70	$6^3/_4$	12	6 x 52	8 x $54^1/_2$	4	2
12	1200	82	$60^7/_8$	$10^9/_{16}$	78	$6^3/_4$	12	6 x $60^3/_4$	8 x 63	4	2

Base unit dimensions (cont)

42CG HORIZONTAL CABINET WITH STAMPED SUPPLY AIR GRILLE, DUCTED REAR RETURN AND HEATER



NOTES:
1. Right hand unit shown; left hand unit opposite.
2. Internal factory valve package and drains may not align with cabinet knockouts.
3. All dimensions ± 1/4-in.
4. Cabinet is Arctic White polyester powder coat paint.

UNIT SIZE	NOM AIRFLOW (Cfm)	DIMENSIONS (in.)						DUCTED REAR RETURN SIZE (in.)	FILTER SIZE (in.)	QTY/UNIT	
		A	B	C	E	F	G			Blower	Motor
02	200	38	17 1/8	10 7/16	34	5 3/4	11	6 x 21 1/2	8 x 23 1/2	1	1
03	300	42	21 1/2	10 1/4	38	5 3/4	11	6 x 25 3/4	8 x 28	1	1
04	400	48	25 7/8	11 1/16	44	5 3/4	11	6 x 30 1/4	8 x 32 1/2	2	1
06	600	53	34 5/8	9 3/16	49	6 3/4	12	6 x 34 1/2	8 x 37	2	1
08	800	60	39	10 1/2	56	6 3/4	12	6 x 39	8 x 41	2	1
10	1000	74	52 1/8	10 15/16	70	6 3/4	12	6 x 52	8 x 54 1/2	4	2
12	1200	82	60 7/8	10 9/16	78	6 3/4	12	6 x 60 3/4	8 x 63	4	2

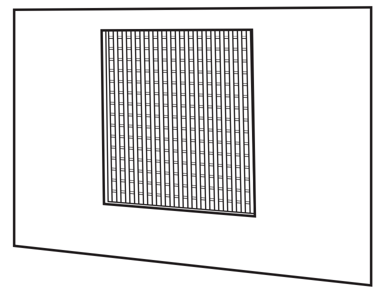
Accessory dimensions

DISCHARGE AIR GRILLES

DISCHARGE GRILLES		
Unit Size	Nominal Airflow (Cfm)	Recommended Grille Sizes (in.) Unit 42C*
02	200	16 x 6
03	300	20 x 6
04	400	26 x 6
06	600	30 x 6
08	800	38 x 6
10	1000	52 x 6
12	1200	60 x 6

*Refer to unit dimensions to size field transitions.

INTEGRAL DOUBLE-DEFLECTION GRILLE FOR HORIZONTAL UNITS (Installed on 42CG Unit as Shown)



Electrical data

ELECTRIC HEATER DATA

HEATER VOLTAGE	HEATER kW									
	0.5	1.0	1.5	2.0	3.0	4.0	5.0	6.0	8.0	10.0
	FLA									
120	4.2	8.3	12.5	16.7	25.0	—	—	—	—	—
208	2.4	4.8	7.2	9.6	14.4	19.2	24.0	28.8	38.5	—
240	2.1	4.2	6.3	8.3	12.5	16.7	20.8	25.0	33.3	41.7
277	1.8	3.6	5.4	7.2	10.8	14.4	18.05	21.7	28.9	36.1

LEGEND
FLA — Full Load Amps
NOTE: All heaters are single-stage and single-phase.

42CA,CE,CG AND CK PSC MOTOR DATA

V-Ph-Hz	FAN SPEED	UNIT SIZE											
		02			03			04			06		
		Nominal Hp	Watts	Amps	Nominal Hp	Watts	Amps	Nominal Hp	Watts	Amps	Nominal Hp	Watts	Amps
115-1-60	H	$^{1}/_{30}$	78	0.53	$^{1}/_{30}$	89	0.83	$^{1}/_{12}$	144	1.40	$^{1}/_{12}$	151	1.40
	M		58	0.31		62	0.50		91	0.70		86	0.72
	L		44	0.27		47	0.34		68	0.45		60	0.45
208-1-60	H	$^{1}/_{30}$	98	0.48	$^{1}/_{30}$	99	0.48	$^{1}/_{12}$	120	0.69	$^{1}/_{12}$	132	0.69
	M		75	0.29		75	0.29		88	0.43		92	0.47
	L		49	0.15		49	0.15		54	0.22		55	0.24
230-1-60	H	$^{1}/_{30}$	114	0.48	$^{1}/_{30}$	112	0.48	$^{1}/_{12}$	137	0.69	$^{1}/_{12}$	150	0.69
	M		87	0.31		86	0.32		104	0.45		111	0.52
	L		57	0.15		57	0.15		62	0.24		65	0.28
277-1-60	H	$^{1}/_{30}$	104	0.35	$^{1}/_{30}$	112	0.35	$^{1}/_{12}$	143	0.69	$^{1}/_{12}$	155	0.69
	M		86	0.26		91	0.26		107	0.43		112	0.43
	L		55	0.16		57	0.16		65	0.25		67	0.35

V-Ph-Hz	FAN SPEED	UNIT SIZE								
		08			10*			12*		
		Nominal Hp	Watts	Amps	Nominal Hp	Watts	Amps	Nominal Hp	Watts	Amps
115-1-60	H	$^{1}/_{6}$	223	2.50	$^{1}/_{12}$ (2)	286	2.80	$^{1}/_{6}$ (2)	399	5.00
	M		166	1.50		184	1.40		307	2.80
	L		83	1.20		134	0.90		166	1.20
208-1-60	H	$^{1}/_{6}$	189	1.30	$^{1}/_{12}$ (2)	245	1.38	$^{1}/_{6}$ (2)	325	2.60
	M		109	0.69		182	0.94		208	1.33
	L		60	0.47		109	0.46		120	0.94
230-1-60	H	$^{1}/_{6}$	206	1.30	$^{1}/_{12}$ (2)	281	1.38	$^{1}/_{6}$ (2)	356	2.60
	M		128	0.70		210	1.00		241	1.34
	L		72	0.50		130	0.50		143	1.00
277-1-60	H	$^{1}/_{6}$	245	0.91	$^{1}/_{12}$ (2)	288	1.38	$^{1}/_{6}$ (2)	426	1.82
	M		152	0.62		219	0.80		293	1.20
	L		120	0.35		132	0.25		234	0.66

*Total motor amps and watts shown for units with 2 motors.

NOTES:
1. Motor nameplate amps may vary.
2. Fan coil units comply with ETL, Canadian Standards Association (CSA), and ETL of Canada standards.

42C HIGH-STATIC PSC MOTOR DATA

SIZE	NOMINAL HP	AMPS	WATTS
42C*02	$^{1}/_{12}$	1.4	59
42C*03	$^{1}/_{12}$	1.4	100
42C*04	$^{1}/_{6}$	2.5	195
42C*06	$^{1}/_{6}$	2.5	195
42C*08	$^{1}/_{5}$	3.6	277
42C*10	$^{1}/_{6}$	5.0	360
42C*12	$^{1}/_{5}$	7.2	513

NOTES:
1. High-static PSC motors are available on 42CA,CE,CK for 60 Hz voltages with a special quote.
2. Motor amps and watts based on 115V motors.

42C ECM MOTOR DATA

SIZE	NOMINAL HP	AMPS			
		120V	208V	230V	277V
42C*02	1/7	2.4	1.4	1.3	1.2
42C*03	1/7				
42C*04	1/6		1.6	1.5	1.0
42C*06	1/6				
42C*08	1/6				
42C*10	1/6 (2)		3.2	3.0	2.0
42C*12	1/6 (2)				

Guide specifications — 42C series

Fan Coil Unit — Horizontal Models

HVAC Guide Specifications — 42C

Size Range: **200 to 1200 Nominal Cfm**

Carrier Model Numbers:

42CA (Furred-in)
42CE (Furred-in with Plenum)
42CG (Cabinet)
42CK (Furred-in, Telescoping Panel)

Part 1 — General

1.01 SYSTEM DESCRIPTION

Horizontal, 2-pipe or 4-pipe (or electric heat), room fan coil unit with furred-in, above ceiling cabinet for ducting, or with cabinet for exposed ceiling installations.

1.02 QUALITY ASSURANCE

Units shall be tested and certified in accordance with AHRI (Air-Conditioning, Heating, and Refrigeration Institute) standard 440, latest edition. All base or standard units shall have C-ETL-US listing signifying the units have been examined by ETL and are in compliance with both the US and Canadian applicable standards. Each coil shall be factory tested for leakage at 300 psig air pressure with coil submerged in water. Insulation and adhesive shall meet NFPA (National Fire Protection Association) 90A requirements for flame spread and smoke generation. All equipment wiring shall comply with NEC (National Electrical Code) requirements.

1.03 DELIVERY, STORAGE AND HANDLING

Each unit shall be individually packaged from point of manufacture. Unit shall be handled and stored in accordance with the manufacturer's instructions.

Part 2 — Products

2.01 EQUIPMENT

A. General:

Factory-assembled, horizontal, blow-thru type fan coil for furred-in, exposed ceiling or ducted installations. Unit shall be complete with water coil(s), fan(s), motor(s), drain pan, and all required wiring, piping, controls and special features. Standard insulation shall be dual density fiberglass insulation.

B. Furred-in Base Unit (42CA):

1. Casing is heavy gage galvanized steel, lined on the inside with $^1/_2$-in. thick fiberglass insulation, with a 1 in. long collar for supply duct connection. NO filter installed in base unit.
2. The drain pan shall be constructed of galvanized steel extending the entire length and width of the coil(s) and shall be pitched for drainage. The inside surface of the drain pan shall be coated with a 2-part closed cell foam insulation.

C. Furred-in Units with Plenum (42CE):

Base unit with factory-installed plenum section and 1-in. fiberglass throwaway filter as shown on equipment drawings. The plenum shall be bottom or rear air return, shall enclose the fan/motor assemblies, and shall be lined with $^1/_2$-in. fiberglass insulation. Unit shall have a removable panel to provide access to fan/motor assemblies and unit identification label.

D. Cabinet Units (42CG):

Base unit with stamped discharge grille, removable bottom access panel with stamped return-air grille, filter rack and 1-in. fiberglass throwaway filter. The panel shall be fastened with tamper proof quarter-turn fasteners. The cabinet shall be coated with an Arctic White powder-coat finish.

E. Ceiling, Furred-in with 2-in. Telescoping Ceiling Panel (42CK):

Base unit with full galvanized upper casing, adjustable height, hinged return-air ceiling panel, and 1-in. fiberglass throwaway filter. Panel shall be coated with an Arctic White powder-coat.

F. Fans:

Direct-driven, double-width fan wheels with forward-curved blades shall be statically and dynamically balanced. Scrolls shall be constructed of galvanized steel. Fan wheels shall be constructed of galvanized steel.

G. Coils:

Standard base unit shall be equipped with a 3-row or 4-row coil for installation in a 2-pipe system. Additional coil depth and circuiting shall be provided for installation in a 4-pipe system as described in the Special Features section. All coils shall have $^1/_2$-in. copper tubes and aluminum fins (10 fins per inch) spacing. Coil fins are mechanical bonded to tube joints. The copper tubes comply with the ASTM (American Society for Testing and Materials) B-75. The fin thickness is 0.0045-in. and tube thickness is 0.016 inch. All coils shall be leak tested with air at 300 psig under water.

H. Controls and Safeties:

The fan motor(s) shall be equipped with integral automatic temperature reset for motor protection.

I. Operating Characteristics:

1. A one-coil unit installed in a 2-pipe system shall be capable of providing heating or cooling as determined by the operating mode of the central water supply system.
2. A double-circuit coil unit installed in a 4-pipe system shall be capable of providing sequenced heating and cooling.

J. Electrical Requirements:

Standard unit shall operate on 115 v, single-phase, 60 Hz electric power. All internal wiring shall be in flexible conduit.

K. Motor(s):

Fan motors shall be 3-speed, 115 v, single-phase, 60 Hz, permanent split capacitor type, permanently lubricated, with sleeve bearings. Motor shall have thermal overload protection with automatic reset and be connected with quick connect electrical plug.

L. Special Features:

Certain standard features are not applicable when the features designated by * are specified. See your local Carrier Sales Offices for amending specifications.

* 1. Unit coil(s) shall be equipped with automatic air vents.

* 2. For installation in a 4-pipe chilled water or direct expansion (DX R-410A) system, unit shall be equipped with a 3-row cooling/one-row heating split-circuit coil, a 3-row cooling/2-row heating split-circuit coil, or a 4-row cooling/one-row heating split-circuit coil as required. Coil connections to be as shown on the equipment drawings.

* 3. For installation on a 2-pipe chilled water or direct expansion (DX R-410A) system, units shall be equipped with a 2-row, 3-row, or 4-row, cooling/heating coil.

* 4. Fan motor shall be permanent split-capacitor type, 208, 220, 240, or 277-v, single-phase, 50 or 60 Hz as specified on the equipment schedule.

* 5. Fan motor shall be constant torque electrically commutated type, 115, 208, 220, 240, or 277-v, single phase, 50 or 60 Hz as specified on the equipment schedule. The operating sequence shall be one of the following, as specified:

   a. 3 Discrete Speed Input, Potentiometer Field Speed Adjustment For use with a 3-speed thermostat.

   b. 4 Discrete Speed Input, Potentiometer Field Speed Adjustment. For use with a 3-speed thermostat.

   c. Variable Airflow for 0 to 10 VDC / 4 to 20 mA Input. Requires a 0 to 10 VDC input signal and is not compatible with a 3-speed thermostat.

* 6. Unit shall be equipped with electric strip heaters mounted on the entering air side of the water coil. Heaters shall include high limit cutout with auto reset and contactor. Capacity and voltage shall be as shown on the equipment schedule. When fan motor and electric heater are selected at the same voltage and connected to a single power source, a junction box and fuse shall be factory furnished and installed to protect the motor and control circuit.

* 7. Filter track and cleanable filter shall be installed in the plenum.

* 8. Drain pan shall include a second drain connection located above the main drain connection to act as an indicator that the main drain is plugged.

* 9. Discharge-air grille with double deflection, aluminum construction with aluminum frame shall be furnished for field installation as shown on the equipment schedule. Aluminum grilles shall have a natural anodized finish (42CG only).

*10. Double-deflection discharge-air grille with steel core assembly shall be factory installed as shown on equipment schedule. Grille shall be painted to match cabinet (42CG only).

11. Manual stop, balancing, combination balance and stop, ball type, and flow control valves shall be factory furnished and installed as indicated on the equipment drawings.

12. Motorized 2-way and 3-way valves shall be factory wired and assembled with tubes terminating in belled ends or unions for field attachment to the coil. Valves shall be packaged within unit to prevent shipping damage.

13. Heating and/or cooling wall thermostat shall be factory furnished for field installation.

14. Automatic changeover device(s) shall be factory wired for field installation on the supply piping.

15. Sequenced heating and cooling wall thermostat shall be factory furnished for field installation.

16. Unit shall operate on 208, 220, 240, or 277-v, single-phase, 50 or 60 Hz electrical power as specified on the equipment schedule. All wiring shall be in flexible metal conduit.

17. Cabinet of 42CG unit or bottom panels of 42CK unit shall be painted with the color specified on the equipment schedule.

18. A stainless steel drain pan shall be available for factory installation.

Guide specifications — 42C series (cont)

19. Factory-installed insulation options shall include foil faced fiberglass or closed cell insulation.
20. Control Options:
    a. 3-speed, 4-position manual fan switch on a wall plate for field-mounting.
    b. Factory-installed 24-v transformer and relay board for use, with 24-v controls by others.
    c. Carrier's Debonair® 24-v digital display programmable or non-programmable thermostat, including factory-installed 24-v transformer, relay board, and changeover sensors, as required. Provides automatic fan speed control based on demand.
    d. Factory-Installed Carrier Fan Coil Open Controller: BACnet* based communicating controller with pre-programmed control algorithms; including factory-installed 24-v transformer, relay board, supply air sensor, return air sensor and changeover sensor (as required). Provides automatic fan speed control based on demand.

*BACnet is a registered trademark of ASHRAE (American Society of Heating, Refrigerating, and Air-Conditioning Engineers).

GREENHECK
Building Value in Air.

Printed Date: 2/21/2017
Job: WPI Student Project
Mark: Floors 1 & 2
Model: RVE-40-36P-30H

RVE-40-36P-30H

CONSTRUCTION FEATURES AND ACCESSORIES

Unit Overview

Model	Supply (CFM)	Outside Air (CFM)	Recirc (CFM)	Exhaust (CFM)	Heating	Cooling	Electrical V/C/P
RVE-40-36P-30H	3,375	3,375	0	3,375	None	Chilled Water	208/60/3

Features

- Exterior housing constructed of galvanized steel
- Energy recovery cassette with a desiccant wheel
- Direct-drive backward inclined plenum blowers with factory mounted VFDs
- Ball bearing motors
- Corrosion resistant fasteners
- Internally lined with galvanized steel metal creating a double wall
- Insulated with 2 in. 2.4# R13 density foam insulation
- Internally mounted control center with motor starters, 24 VAC control transformer(s), control circuit fusing
- Energy Wheel Motor: 1/20 HP
- Stainless steel condensate drain pan and connection.

Options and Accessories

- UL\cUL1995
- Frost Control: Timed Exhaust
- Weatherhood: Downturned Hood
- Outdoor Air Filters - MERV 8, 4-25x20x2
- Exhaust Air Filters - MERV 8, 4-25x20x2
- Supply Filters - 2" Pleated MERV 8, 4-20x20x2
- Roof Curbs - GKD-47.19/144.96-G14"
- Outdoor Air Dampers - Motorized Low Leakage
- Painted Exterior - Permatector Concrete Gray (RAL 7023)
- Microprocessor Controls
- Supply Fan Controls - Constant Volume (on/off)
- Exhaust Fan Controls - Constant Volume
- Unit Disconnect - Mounted By Factory
- Exhaust Discharge Gravity Backdraft Damper

Note: Unit is provided with factory mounted and wired disconnect switch.

Note: The chilled water coil is located before the heating element. Greenheck recommends draining the chilled water coil in the winter.

GREENHECK
Building Value in Air.

Printed Date: 2/21/2017
Job: WPI Student Project
Mark: Floors 1 & 2
Model: RVE-40-36P-30H

PERFORMANCE AND SPECIFICATIONS

Description/Arrangement

Model	Qty	Unit Weight (lb)	Outdoor Air Discharge	Outdoor Air Intake	Exhaust Air Discharge	Return Air Intake
RVE-40-36P-30H	1	2,380	Bottom	End	Side	Bottom

Design Conditions

Elevation (ft)	Summer DB (F)	Summer WB (F)	Winter DB (F)
30	91	76	7

Air Performance

Type	Volume (CFM)	External SP (in. wg)	Total SP (in. wg)	RPM	Operating Power (hp)	Motor Qty/Size (hp)	Size (in.)/ Type
Supply	3,375	1.5	3.526	1991	3.03	Qty 1 (5)	18/Plenum
ExhaustNormal	3,375	1.5	3.08	2200	3.62	Qty 1 (5)	18/Plenum

Electrical/Motor Specifications

V/C/P	Unit MCA (amps)	Unit MOP (amps)	Enclosure	Supply Motor RPM	Supply Efficiency	Exhaust Motor RPM	Exhaust Efficiency
208/60/3	38.2	50	ODP	1750	PE	1750	PE

Cooling Specifications

Cooling Type	Entering Air (F)		Leaving Air (F)		Capacity (MBH)		Fluid Temps (F)	
	Dry-bulb	Wet-bulb	Dry-bulb	Wet-bulb	Total	Sensible	Entering	Leaving
Chilled Water	81.6	69.0	56.4	56.0	142.2	93.6	45.0	55.0
CW Coil Model		Fins Per Inch	Rows Deep	Fluid Type	Face Vel. (ft/min):	Air Press. Drop (in. wg):	Fluid Flow (GPM)	Fluid Press. Drop (ft wg)
CW58S04H10-42x37-RH		10	4	Water	313	0.322	28.3	3.4

Sound Performance in Accordance with AMCA

Fan	Sound Power by Octave Band								Lwa	dBA	Sones
	62.5	125	250	500	1000	2000	4000	8000			
Supply	79	81	92	83	81	78	77	71	88	76	26
Exhaust Normal	76	81	85	79	76	75	74	70	83	72	20

Unit Pressure Drop (in. wg)

Air Stream	Weatherhood	Damper Section	Filter Section	Cooling Section	Heating Section
Supply	0.124	0.048	0.179	0.322	0
Exhaust	0.227	0	0	N/A	N/A

Note: The unit base line performance incorporates the pressure drop of the energy wheel.

Note: Filter pressure drop is based off of clean filters.

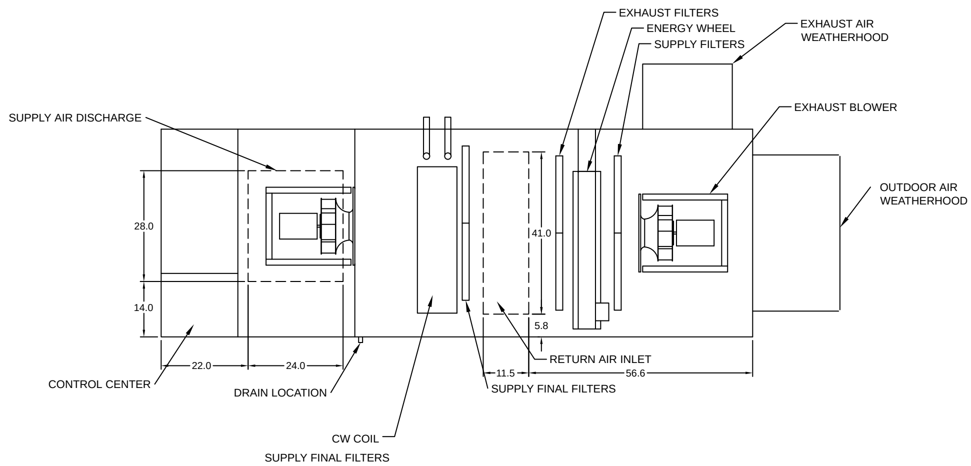
GREENHECK
Building Value in Air.

Printed Date: 2/21/2017
Job: WPI Student Project
Mark: Floors 1 & 2
Model: RVE-40-36P-30H

RADIATED SOUND

Position C

Position D



Position B

Plan

Position A

Position E = Top of Unit

RVE-40: Supply Air Flow Nominal, Largest Tonnage Condensing Section Available, PDX units only

Free Field Plane	Octave Band (Sound Power Lw)								Lw	LwA
	1	2	3	4	5	6	7	8		
A	73	86	81	79	77	73	69	63	89	82
B	71	79	77	71	69	64	63	55	82	75
C	79	76	69	66	64	59	53	46	81	69
D	74	77	72	72	69	62	58	51	81	74
E	77	84	80	76	76	70	66	60	87	80
Total	83	89	85	82	81	76	72	65	92	85

AMCA 320-07 - Laboratory Methods of Sound Testing of Fans Using Sound Intensity
Tests conducted in accordance with this standard.
Free field measurement plane created 1 foot from unit on all sides and top.
Sound Intensity measured in Watts/m^2.
Sound data converted to Sound Power (Lw) for the chart above.
A-Weighted Sound Power was determined using AMCA Standard 301-90 Clause 9.1.

GREENHECK
Building Value in Air.

Printed Date: 2/21/2017
Job: WPI Student Project
Mark: Floors 1 & 2
Model: RVE-40-36P-30H

COOLING PERFORMANCE

Chilled Water Cooling

Cooling Type	Entering Air (F)		Leaving Air (F)		Capacity (MBH)		Fluid Temps (F)	
	Dry-bulb	Wet-bulb	Dry-bulb	Wet-bulb	Total	Sensible	Entering	Leaving
Chilled Water	81.6	69.0	56.4	56.0	142.2	93.6	45.0	55.0

CW Coil Model	Fins Per Inch	Rows Deep	Fluid Type	Face Vel. (ft/min):	Air Press. Drop (in. wg):	Fluid Flow (GPM)	Fluid Press. Drop (ft wg)
CW58S04H10-42x37-RH	10	4	Water	313	0.322	28.3	3.4

Chilled Water Unit Details

The RVE will come equipped with the following:

- Aluminum fins
- Copper tubes
- Hand brazed construction
- Galvanized steel casing

Chilled Water Coil Details

Cooling Coil Model:	CW58S04H10-42x37-RH
Rows Deep:	4
Fins Per Inch:	10
Face Velocity (ft/min):	313
Total Energy (MBH):	142.2
Sensible Capacity (MBH):	93.6
Entering Dry Bulb (F):	81.6
Entering Wet Bulb (F):	69.0
Leaving Dry Bulb (F):	56.4
Leaving Wet Bulb (F):	56.0
Cool Coil SP (in. wg):	0.322
Entering Fluid (F):	45.0
Leaving Fluid (F):	55.0
Fluid Type:	Water
Glycol (%):	0
Fluid Flow (GPM):	28.3
Fluid PD (ft wg):	3.4
Connection Size (in.):	1.5

GREENHECK
Building Value in Air.

Printed Date: 2/21/2017
Job: WPI Student Project
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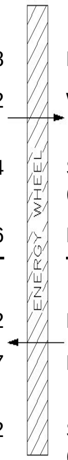
Model: RVE-40-36P-30H

ENERGY RECOVERY SUMMER PERFORMANCE

OUTDOOR AIR

Entering Air		Leaving Air	
Dry Bulb (F)	90.8	Dry Bulb (F)	81.6
Wet Bulb (F)	76.2	Wet Bulb (F)	69.0
Specific Humidity (gr/lb)	114	Specific Humidity (gr/lb)	87
Enthalpy (BTU/lb)	39.6	Enthalpy (BTU/lb)	33.0



Leaving Air		Entering Air	
Dry Bulb (F)	84.2	Dry Bulb (F)	75.0
Wet Bulb (F)	70.7	Rel. Humidity (%)	50
Specific Humidity (gr/lb)	92	Specific Humidity (gr/lb)	65
Enthalpy (BTU/lb)	34.8	Enthalpy (BTU/lb)	28.1

EXHAUST AIR

Design Air Flow Conditions

Model	Outdoor Air Volume (CFM)	Outdoor Air Wheel Effectiveness	Exhaust Air Volume (CFM)	Exhaust Air Wheel Effectiveness
RVE-40-36P-30H	3,375	57.8	3,375	57.8

Outdoor Air Cooling Reduction

	(BTU/h)	(tons)
OA Load w/o Energy Recovery	249,075.0	20.76
OA Load with Energy Recovery	148,838.0	12.40
Equipment Reduction tons		8.35

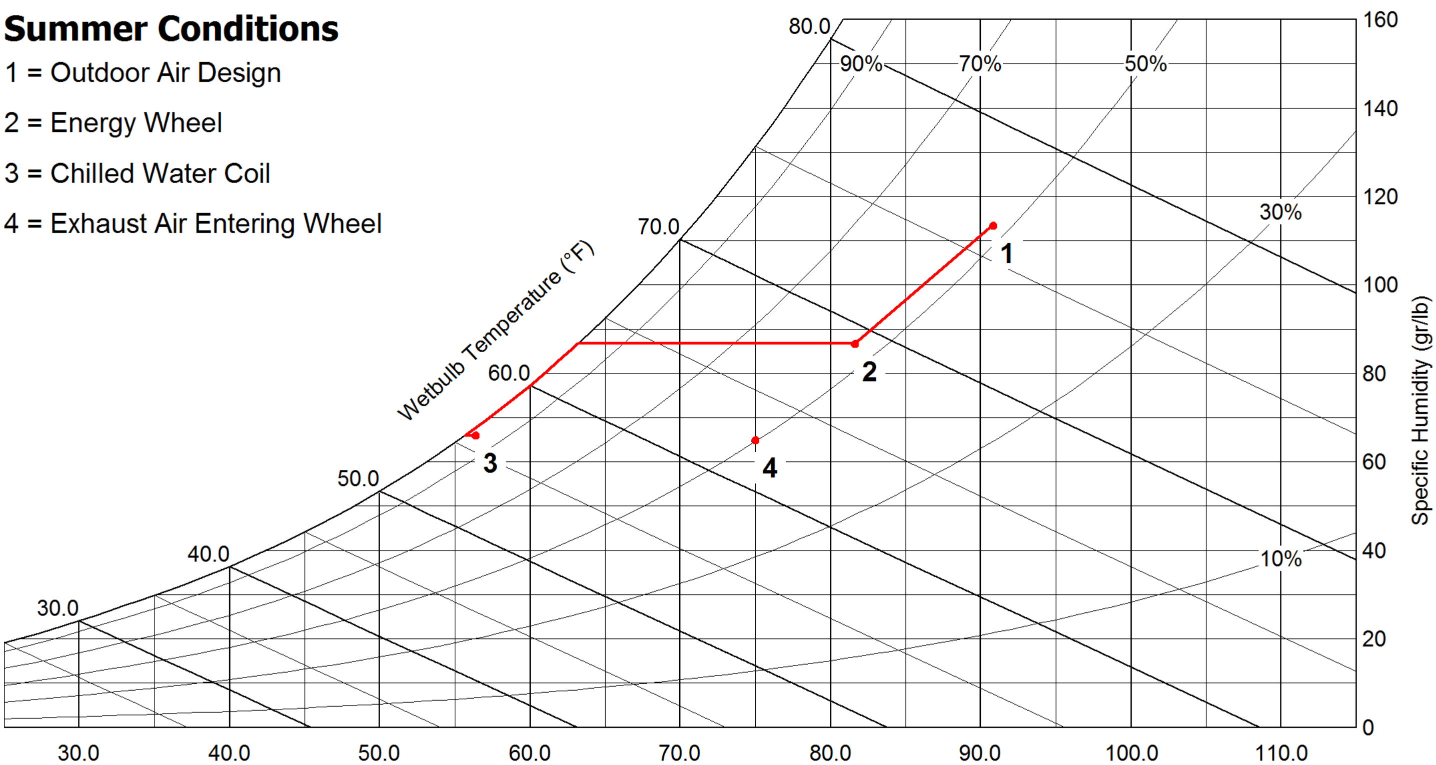
Summer Conditions

1 = Outdoor Air Design

2 = Energy Wheel

3 = Chilled Water Coil

4 = Exhaust Air Entering Wheel



GREENHECK
Building Value in Air.

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Model: RVE-40-36P-30H

ENERGY RECOVERY WINTER PERFORMANCE

OUTDOOR AIR

Entering Air		Leaving Air	
Dry Bulb (F)	7.4	Dry Bulb (F)	45.2
Wet Bulb (F)	5.3	Wet Bulb (F)	38.6
Specific Humidity (gr/lb)	4	Specific Humidity (gr/lb)	24
Enthalpy (BTU/lb)	2.4	Enthalpy (BTU/lb)	14.9

ENERGY WHEEL

Leaving Air		Entering Air	
Dry Bulb (F)	34.2	Dry Bulb (F)	72.0
Wet Bulb (F)	31.1	Rel. Humidity (%)	35
Specific Humidity (gr/lb)	21	Specific Humidity (gr/lb)	41
Enthalpy (BTU/lb)	11.2	Enthalpy (BTU/lb)	23.7

EXHAUST AIR

Design Air Flow Conditions

Model	Outdoor Air Volume (CFM)	Outdoor Air Wheel Effectiveness	Exhaust Air Volume (CFM)	Exhaust Air Wheel Effectiveness
RVE-40-36P-30H	3,375	58.8	3,375	58.8

Outdoor Air Heating Reduction

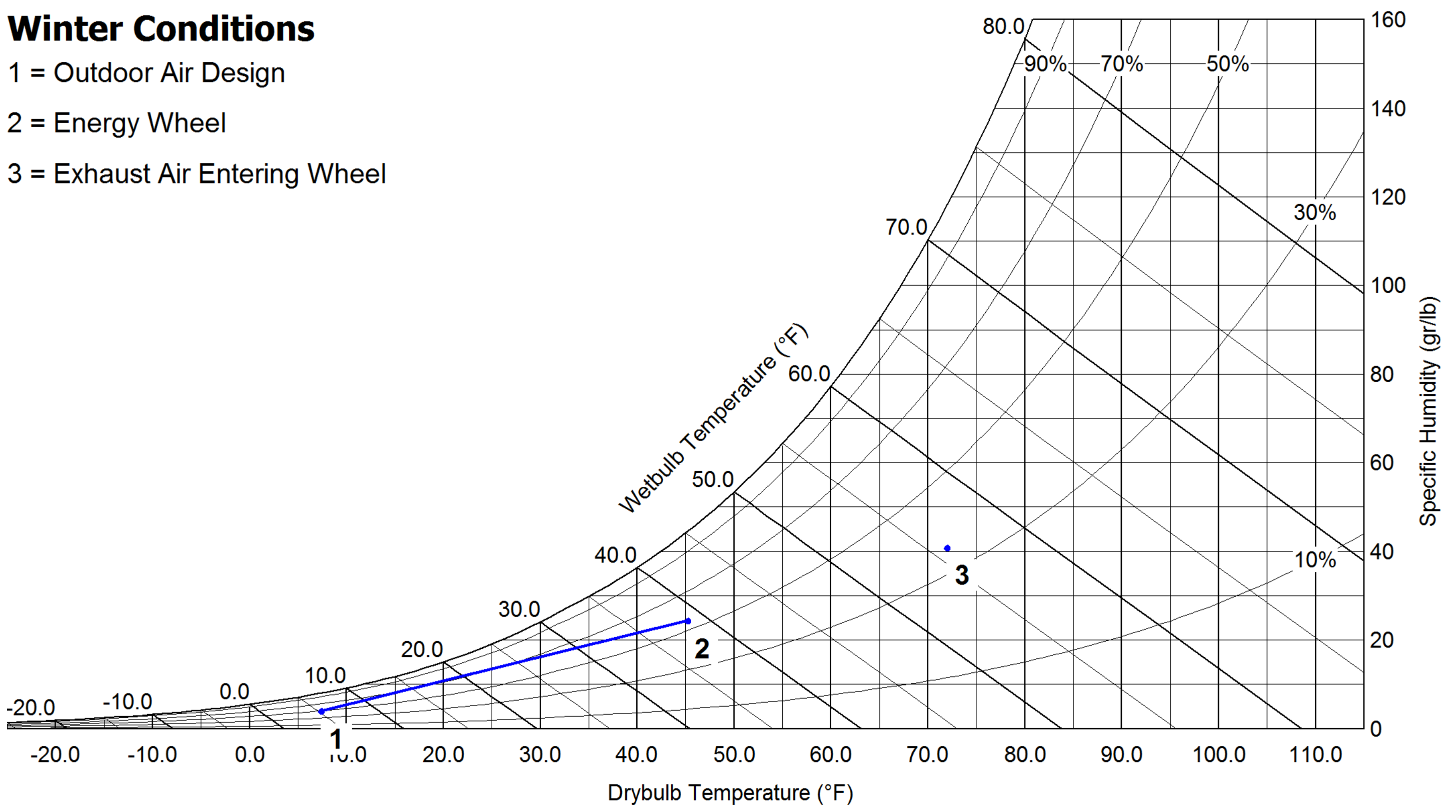
	(BTU/h)
OA Load w/o Energy Recovery	235,467.0
OA Load with Energy Recovery	97,686.0
BTU/h Reduction	137,781.0

Winter Conditions

1 = Outdoor Air Design

2 = Energy Wheel

3 = Exhaust Air Entering Wheel



GREENHECK
Building Value in Air.

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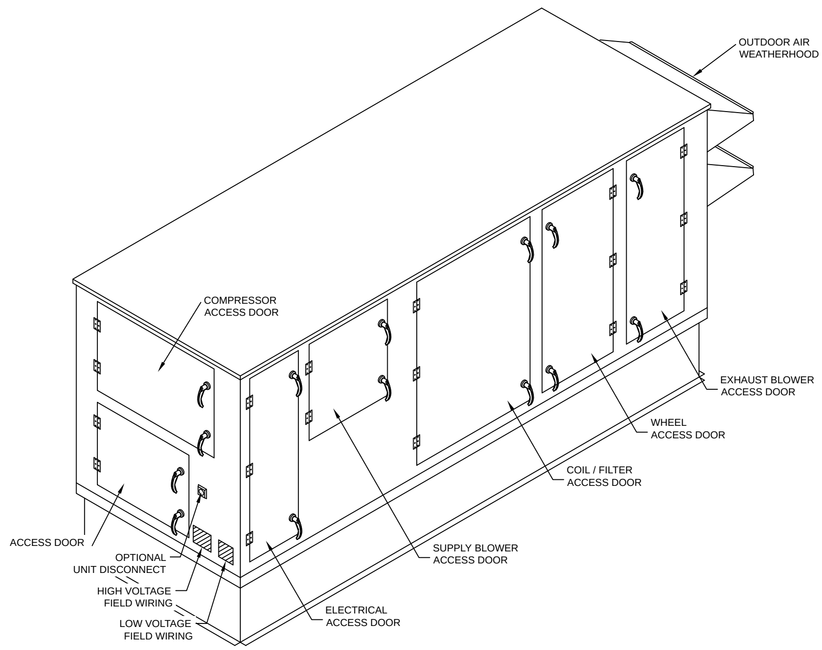
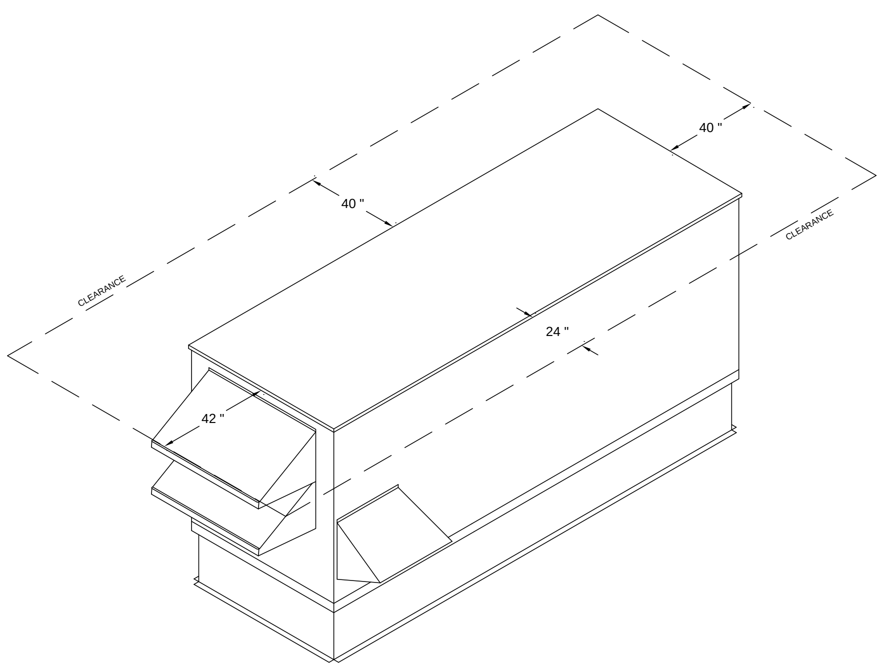
ISOMETRIC DRAWINGS



Back Right Isometric



Front Left Isometric

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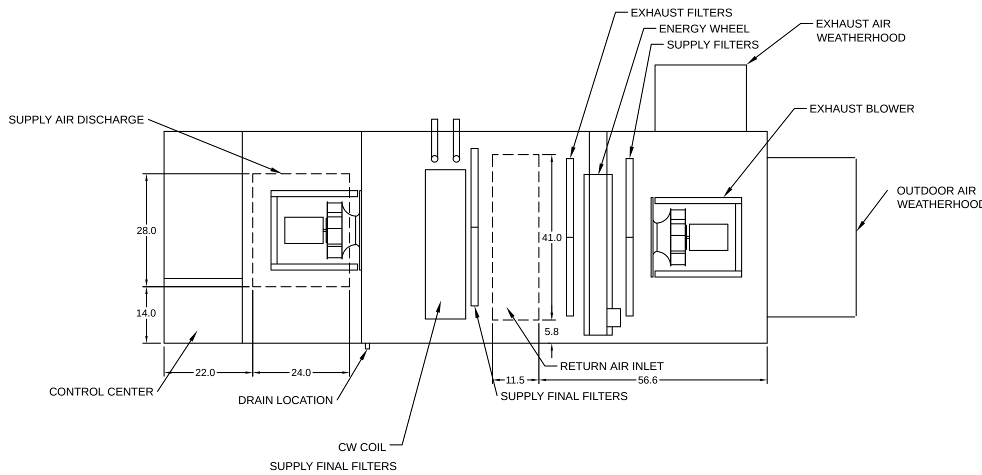
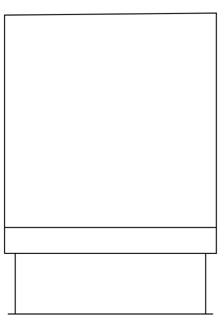
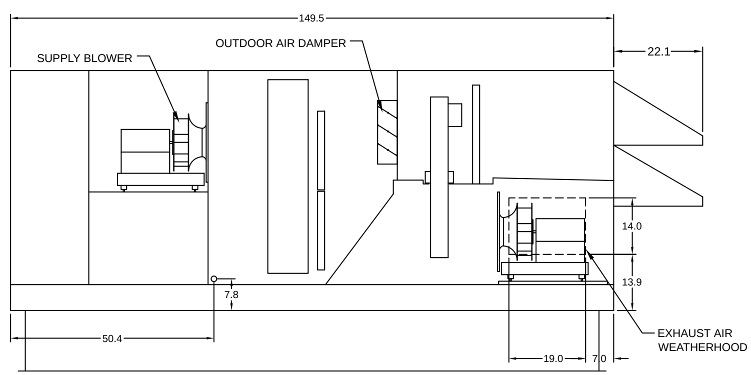
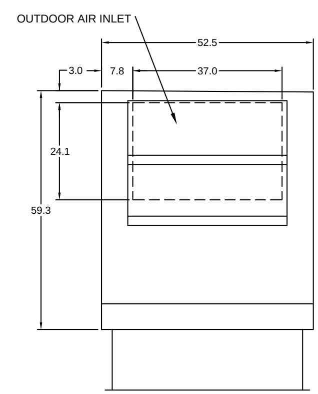
OVERVIEW DRAWINGS



Plan







Left End

Elevation

Right End

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Building Value in Air.

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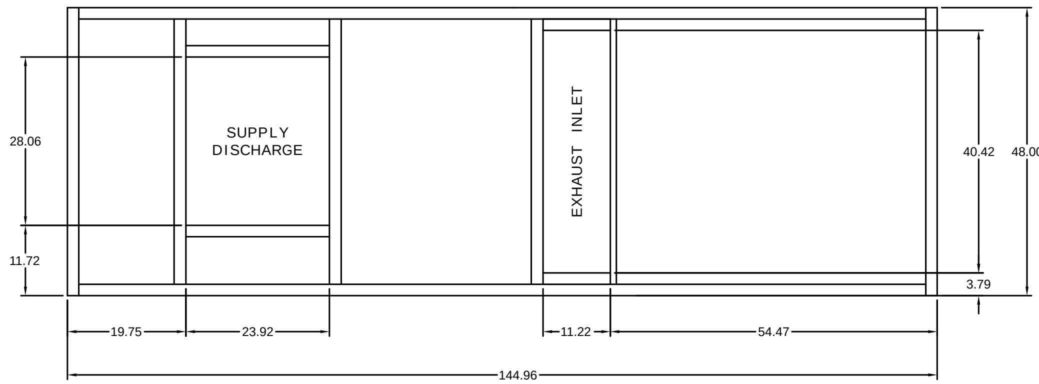
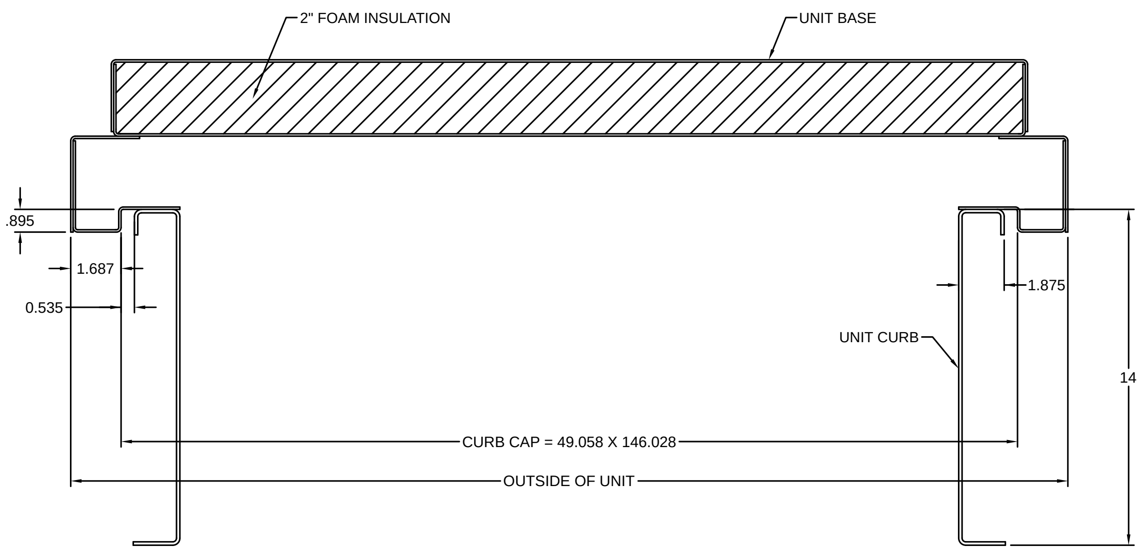
FOOTPRINT DRAWINGS

Top View of Curb



Cross-Section View of Unit on Curb



NOTES: All dimensions shown are in units of in.'s
If unit is selected with side or end discharge/return, there will not be bottom connections supplied with the curb.

Curb Weight: 218 lb

GREENHECK
Building Value in Air.

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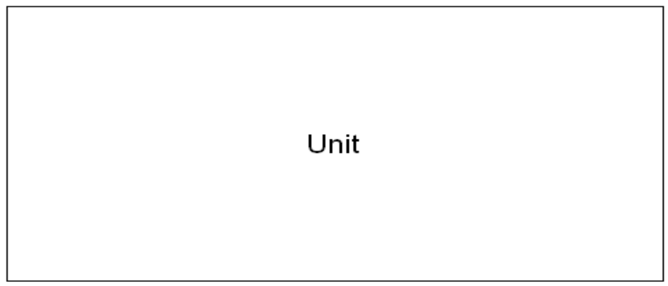
Corner Weights

561 lb 622 lb



567 lb 630 lb

Note: Estimated corner weights are shown looking down on unit and the outside air intake will be on the right. Weights are applied at the base of the unit. Images not drawn to scale.

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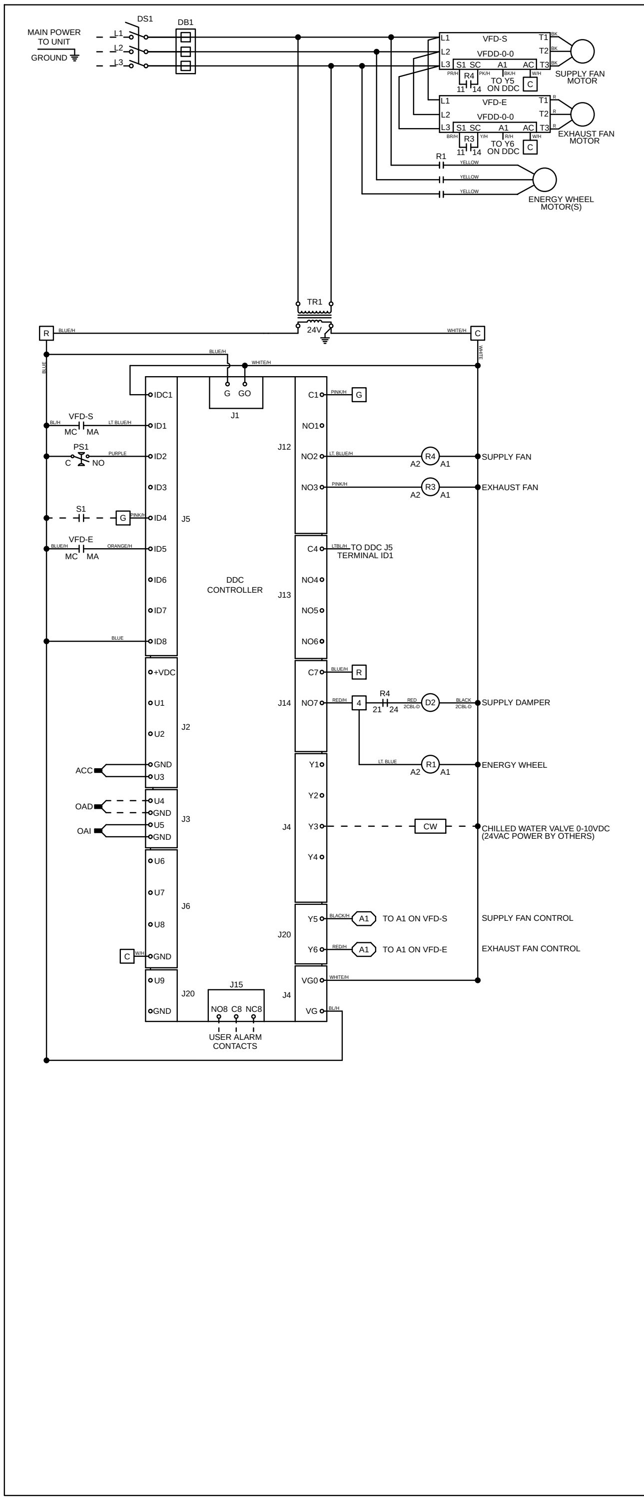
WIRING DIAGRAM



GREENHECK
Building Value in Air.

Wiring Diagram Code:
G33FF1100NXCXXXF13

CAUTION

UNIT SHALL BE GROUNDED IN ACCORDANCE WITH N.E.C.
POWER MUST BE OFF WHILE SERVICING.

NOTES

USE COPPER CONDUCTORS ONLY
60° C FOR TERMINALS RATED LESS THAN 100 AMPS.
75° C FOR TERMINALS RATED 100 AMPS OR MORE.
FIELD CONTROL WIRING RESISTANCE SHOULD NOT EXCEED 0.75 OHM.
FIELD WIRED – – – – –
FACTORY SUPPLIED AND WIRED ————

WIRE COLOR CODE

BK	BLACK	BL	BLUE	BR	BROWN
GY	GRAY	LT BL	LIGHT BLUE	O	ORANGE
PK	PINK	PR	PURPLE	R	RED
W	WHITE	Y	YELLOW		

LEGEND

ACC	AFTER COOLING COIL TEMP
D#	DAMPER
DB#	POWER DISTRIBUTION BLOCK
DS	DISCONNECT SWITCH
OAD	OUTDOOR AIR DISHCHARGE TEMP
OAI	OUTDOOR AIR INLET TEMP
PS1	WHEEL FROST PRESSURE SWITCH
R1	ENERGY WHEEL CONTACTOR
R3	EXHAUST BLOWER VFD RELAY
R4	SUPPLY BLOWER VFD RELAY
S1	FAN SWITCH
TR#	TRANSFORMER
VFD	VARIABLE FREQUENCY DRIVE

DDC Code: Version - TAP v 2.40
GWXCX100 XNXN

Wiring Template: F13

GREENHECK
Building Value in Air.

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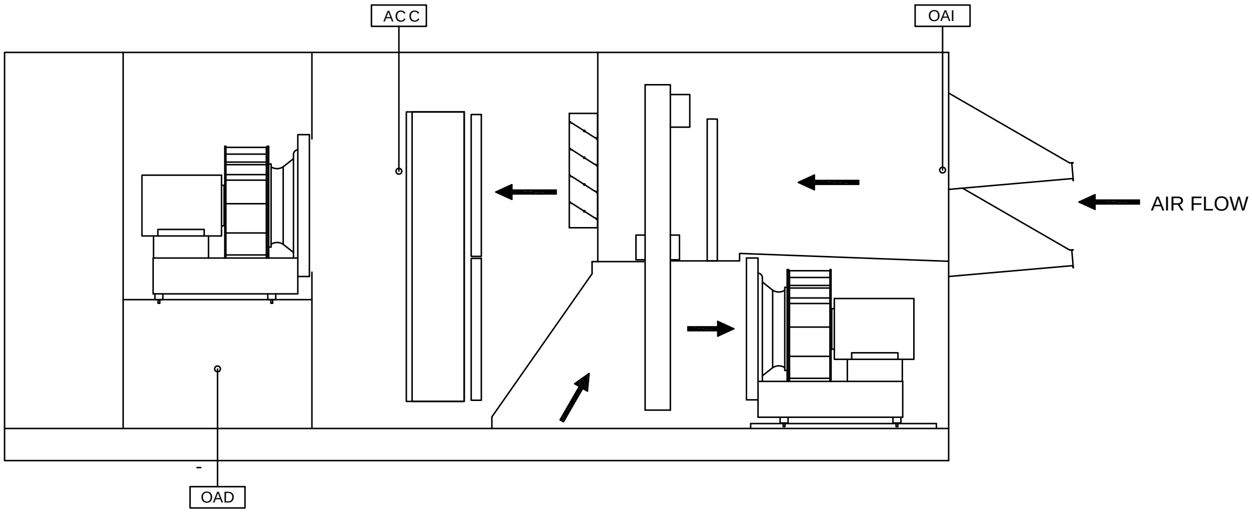
MONITORING POINTS



Item	Description	Type
OAI	Outdoor Air Intake Temperature Sensor	10K Ohm NTC (Carel)
OAD	Outdoor Air Discharge Temperature Sensor	10K Ohm NTC (Carel)
ACC	After Cooling Coil Temperature Sensor	10K Ohm NTC (Carel)

*Shipped loose sensor.

GREENHECK
Building Value in Air.

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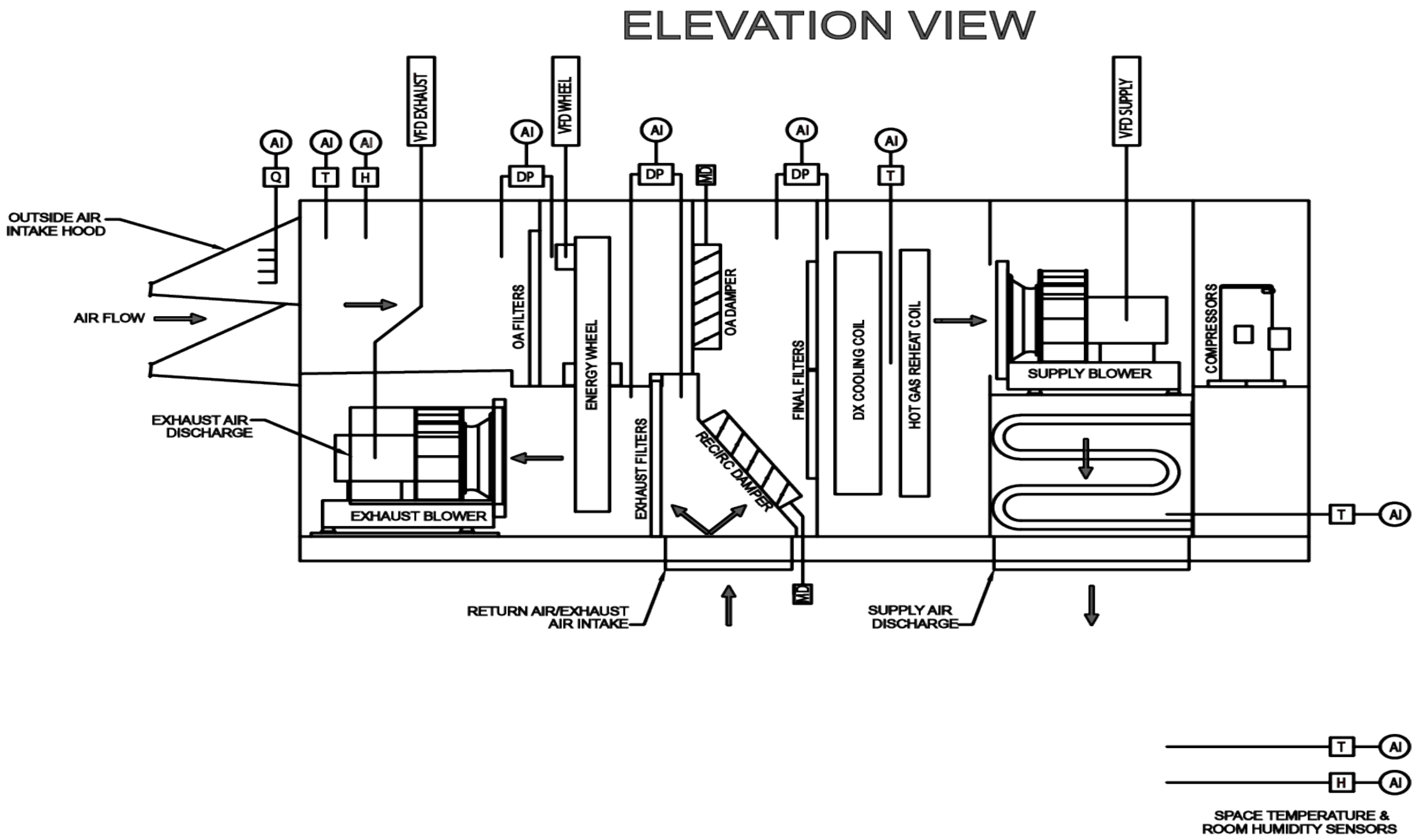
SENSOR LOCATIONS



GREENHECK
Building Value in Air.

Printed Date: 2/21/2017
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Model: RVE-40-36P-30H

Microprocessor Controller Sequence of Operation

MICROPROCESSOR CONTROLLER: Controller shall be provided with required sensors and programming for rooftop unit. Controller shall be factory programmed, mounted and tested. Controller shall have a LCD readout for changing set points and monitoring unit operation.

UNIT START COMMAND (Unit will be enabled to start once a jumper is placed between R to G):

- Factory mounted and wired outdoor air damper actuator is powered
- Exhaust fan starts after a 10 second (adj.) delay.
- Supply fan starts 10 second delay.
- Tempering options and energy wheel option to function as described below.

UNIT STOP COMMAND (OR DE-ENERGIZED):

- Supply fan, exhaust fan, energy wheel and tempering options de-energized.
- Outdoor air damper actuator is spring return close.

OCCUPIED/UNOCCUPIED MODES: Shall be based on a 7-day time clock internal to the controller. The schedule shall be set by the end user. When a user initiates an override input, the controller will switch from unoccupied to occupied mode. The controller will return to the scheduled occupied/unoccupied mode after the override time has expired (60 min, adj.). If internal time clock is disabled, a remote contact or a BMS can control the occupied/ unoccupied mode.

Occupied Mode:

- Damper control per below.
- Energy wheel control per below.
- Exhaust fan ON.
- Supply fan ON.
- Cooling per below.

Unoccupied Mode (Unit Off): Unit remains off when in unoccupied mode.

- Supply fan OFF
- Exhaust fan OFF
- Tempering OFF
- Outdoor air damper closed.

Morning Warm-up: One hour prior to occupancy, the controller will reference the temperature differential between the current room temperature and the occupied temperature set point. The controller will then look at the amount of time required from the previous days morning warm up sequence and determine how far in advance the unit has to be started to meet the desired ocupied set point by the time of occupancy.

SUPPLY BLOWER SEQUENCE: The supply blower is provided with a factory mounted variable frequency drive. The supply blower speed will be controlled with the following sequence.

Constant Volume (on/off): The supply blower will operate at a constant speed set point (adj.) during operation.

EXHAUST BLOWER SEQUENCE: The exhaust blower is provided with a factory mounted variable frequency drive. The exhaust blower speed will be controlled with the following sequence.

Constant Volume (on/off): The exhaust blower will operate at a constant speed set point (adj.) during operation.

COOLING SEQUENCE: The cooling is controlled to maintain the supply temperature set point. The mechanical cooling will be locked out when the outside air is < 55°F - 2°F hysteresis (adj.).

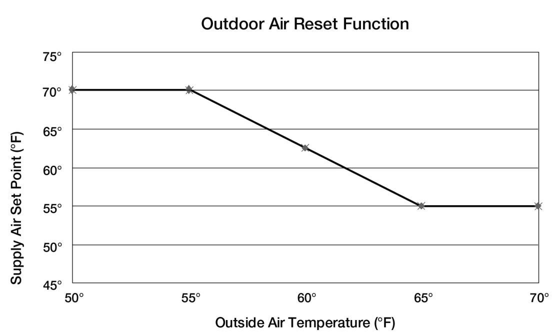
Chilled Water: The controller will modulate a chilled water valve (field provided) to maintain the supply air set point (adj.). Main power to the valve must be provided in field. **Coil Freeze protection must be provided by others in the field!**

DEHUMIDIFICATION SEQUENCE: The cooling is controlled to maintain the cooling-coil set point. The dehumidification sequence will be locked out when the OA is <10°F above the cold-coil set point (adj.).

Cold Coil Setpoint Reset Function: The controller will control the cooling to maintain an active set point. The active set point will set to local control (55° F, adj) from the factory and can be field adjusted to the following sequence:

SUPPLY SET POINT RESET FUNCTION. The controller will modulate the heating and cooling to maintain an active set point. The active set point will be set to outdoor air reset from the factory and can be field adjusted to the following sequence:

OA Reset (Default): The controller will monitor the outdoor air temperature and adjusts the desired supply temperature set point accordingly. For example, when the outdoor air is below 55 °F, the controller will change the supply set point to 70 °F. If the outdoor air is above 65 °F, the controller will change the supply set point to 55°F. If the outdoor air temperature is between 55°F and 65°F, the supply set point changes according to the outdoor air reset function. A visual representation of this is shown below.



Local: The supply set point will be a constant temperature set from the controller (adj.).

BUILDING FREEZE PROTECTION: If the supply air temperature drops below 35°F (adj.) for 300s (adj.), the controller will de-energize the unit and activate the alarm output.

TEMPERATURE PROTECTION: The controller will enable the supply fan to modulate down to help the unit keep up with heating demand in the event of wheel failure or the unit operating outside design conditions. (This can be enabled under the manufacturer menu in the controller)

FROST CONTROL: Frost control for the energy wheel is enabled when frost is present on the wheel; based on the outside air temperature and the pressure drop across the wheel. If the outdoor air temperature is below 5°F – 2°F hysteresis, adj. and the differential pressure across the wheel is about 1.5", adj. frost control will enable.

Timed Exhaust: When frosting is occurring, the supply blower is cycled (30 min. ON / 5 min. OFF, adj.) to allow the warm exhaust air to defrost the wheel. Once either the pressure drop decreases below the pressure switch set point, or the outdoor air temperature increases above the temperature set point, the unit will resume normal operation.

ALARMS INDICATION: The controller will display alarms and have one digital output for remote indication of an alarm condition. Possible alarms include:

Dirty Wheel Alarm: The controller monitors pressure across the wheel and sends an alarm in the case of an increased pressure drop.

Supply and Exhaust Air Alarm: The controller monitors the proving switch on each blower and sends an alarm in the case of either blower proving switch not engaging for 30s (adj.).

Temperature Sensor Alarm: The controller sends an alarm in the case of a failed air temperature sensor.

Accessories: The following accessories will be included with the unit to expand the functionality or usability of the controller.

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Model: RVE-40-36P-30H

Unit Warranty

Limited Warranty

Greenheck warrants this equipment to be free from defects in material and workmanship for a period of 1 year(s) from the purchase date. The energy recovery wheel is warranted to be free from defects in material and workmanship for a period of five years from the purchase date. Any component which proves defective during the warranty period will be repaired, or replaced, at Greenheck's sole option when returned to our factory, transportation prepaid.

The warranty does not include labor costs associated with troubleshooting, removal, or installation. Greenheck will not be liable for any consequential, punitive, or incidental damages resulting from use, repair, or operation of any Greenheck product.

This warranty is exclusive, and is in lieu of all other warranties, whether written, oral or implied, including the warranty of merchantability and the warranty of fitness for a particular purpose.

GREENHECK
Building Value in Air.

Printed Date: 2/21/2017
Job: WPI Student Project
Mark: Floor 3
Model: RVE-120-74P-30H

RVE-120-74P-30H

CONSTRUCTION FEATURES AND ACCESSORIES

Unit Overview

Model	Supply (CFM)	Outside Air (CFM)	Recirc (CFM)	Exhaust (CFM)	Heating	Cooling	Electrical V/C/P
RVE-120-74P-30H	13,480	13,480	0	13,480	Hot Water	Chilled Water	208/60/3

Features

- Exterior housing constructed of galvanized steel
- Energy recovery cassette with a desiccant wheel
- Direct-drive backward inclined plenum blowers with factory mounted VFDs
- Ball bearing motors
- Corrosion resistant fasteners
- Internally lined with galvanized steel metal creating a double wall
- Insulated with 2 in. 2.4# R13 density foam insulation
- Internally mounted control center with motor starters, 24 VAC control transformer(s), control circuit fusing
- Energy Wheel Motor: 1/6 HP
- Stainless steel condensate drain pan and connection.

Options and Accessories

- UL\cUL1995
- Frost Control: Timed Exhaust
- Weatherhood: Downturned Hood
- Outdoor Air Filters - MERV 8, 8-20x20x2
- Exhaust Air Filters - MERV 8, 8-20x20x2
- Supply Filters - 2" Pleated MERV 8, 12-16x20x2
- Outdoor Air Dampers - Motorized Low Leakage
- Painted Exterior - Permatector Concrete Gray (RAL 7023)
- Microprocessor Controls
- Supply Fan Controls - Constant Volume (on/off)
- Exhaust Fan Controls - Constant Volume
- Branch Circuit Fusing
- Unit Disconnect - Mounted By Factory
- Short-circuit current - 5kA
- Exhaust Discharge Gravity Backdraft Damper

Note: Unit is provided with factory mounted and wired disconnect switch.

GREENHECK
Building Value in Air.

Printed Date: 2/21/2017
Job: WPI Student Project
Mark: Floor 3
Model: RVE-120-74P-30H

PERFORMANCE AND SPECIFICATIONS

Description/Arrangement

Model	Qty	Unit Weight (lb)	Outdoor Air Discharge	Outdoor Air Intake	Exhaust Air Discharge	Return Air Intake
RVE-120-74P-30H	1	5,995	Bottom	End	Side	Bottom

Design Conditions

Elevation (ft)	Summer DB (F)	Summer WB (F)	Winter DB (F)
30	91	76	7

Air Performance

Type	Volume (CFM)	External SP (in. wg)	Total SP (in. wg)	RPM	Operating Power (hp)	Motor Qty/Size (hp)	Size (in.)/ Type
Supply	13,480	0.5	3.923	2282	7.66	Qty 2 (10)	20/Plenum
ExhaustNormal	13,480	0.5	2.312	2309	7.62	Qty 2 (10)	20/Plenum

Electrical/Motor Specifications

V/C/P	Unit MCA (amps)	Unit MOP (amps)	Enclosure	Supply Motor RPM	Supply Efficiency	Exhaust Motor RPM	Exhaust Efficiency
208/60/3	132.1	150	ODP	1770	PE	1770	PE

Heating/Cooling Specifications

Heating Type	Entering Air Temp. (F)	Leaving Air Temp. (F)	Fluid Type	Face Velocity (ft/min)	Air Pressure Drop (in. wg)	Entering Fluid Temp. (F)	Leaving Fluid Temp. (F):
Hot Water	48.0	104.7	Water	555	0.145	180.0	160.0
HW Coil Model		Total Energy (MBH)	Fins Per Inch	Rows Deep	Connection Size (in.)	Fluid Flow Rate (GPM)	Fluid Press. Drop (ft wg)
HW12C02H10-70x50-RH		826.9	10	2	2.5	84.6	10.7

Cooling Type	Entering Air (F)		Leaving Air (F)		Capacity (MBH)		Fluid Temps (F)	
	Dry-bulb	Wet-bulb	Dry-bulb	Wet-bulb	Total	Sensible	Entering	Leaving
Chilled Water	80.9	69.0	56.7	56.0	564.8	359.7	45.0	55.0
CW Coil Model		Fins Per Inch	Rows Deep	Fluid Type	Face Vel. (ft/min):	Air Press. Drop (in. wg):	Fluid Flow (GPM)	Fluid Press. Drop (ft wg)
CW12C06F10-70x50-RH		10	6	Water	555	0.721	112.6	8.1

Sound Performance in Accordance with AMCA

Fan	Sound Power by Octave Band								Lwa	dBA	Sones
	62.5	125	250	500	1000	2000	4000	8000			
Supply	59	72	87	93	97	94	89	83	100	89	49
Exhaust Normal	56	71	80	88	89	86	83	79	93	81	31

Unit Pressure Drop (in. wg)

Air Stream	Weatherhood	Damper Section	Filter Section	Cooling Section	Heating Section
Supply	0.445	0.035	0.918	0.721	0.145
Exhaust	0.229	0	0.423	N/A	N/A

Note: The unit base line performance incorporates the pressure drop of the energy wheel.

Note: Filter pressure drop is based off of clean filters.

GREENHECK
Building Value in Air.

Printed Date: 2/21/2017
Job: WPI Student Project
Mark: Floor 3
Model: RVE-120-74P-30H

COOLING PERFORMANCE

Chilled Water Cooling

Cooling Type	Entering Air (F)		Leaving Air (F)		Capacity (MBH)		Fluid Temps (F)	
	Dry-bulb	Wet-bulb	Dry-bulb	Wet-bulb	Total	Sensible	Entering	Leaving
Chilled Water	80.9	69.0	56.7	56.0	564.8	359.7	45.0	55.0

CW Coil Model	Fins Per Inch	Rows Deep	Fluid Type	Face Vel. (ft/min):	Air Press. Drop (in. wg):	Fluid Flow (GPM)	Fluid Press. Drop (ft wg)
CW12C06F10-70x50-RH	10	6	Water	555	0.721	112.6	8.1

Chilled Water Unit Details

The RVE will come equipped with the following:
- Aluminum fins
- Copper tubes
- Hand brazed construction
- Galvanized steel casing

Chilled Water Coil Details

Cooling Coil Model:	CW12C06F10-70x50-RH
Rows Deep:	6
Fins Per Inch:	10
Face Velocity (ft/min):	555
Total Energy (MBH):	564.8
Sensible Capacity (MBH):	359.7
Entering Dry Bulb (F):	80.9
Entering Wet Bulb (F):	69.0
Leaving Dry Bulb (F):	56.7
Leaving Wet Bulb (F):	56.0
Cool Coil SP (in. wg):	0.721
Entering Fluid (F):	45.0
Leaving Fluid (F):	55.0
Fluid Type:	Water
Glycol (%):	0
Fluid Flow (GPM):	112.6
Fluid PD (ft wg):	8.1
Connection Size (in.):	2.5

GREENHECK
Building Value in Air.

Printed Date: 2/21/2017
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Model: RVE-120-74P-30H

HEATING PERFORMANCE

Hot Water Heating

Heating Type	Entering Air Temp. (F)	Leaving Air Temp. (F)	Fluid Type	Face Velocity (ft/min)	Air Pressure Drop (in. wg)	Entering Fluid Temp. (F)	Leaving Fluid Temp. (F):
Hot Water	48.0	104.7	Water	555	0.145	180.0	160.0
HW Coil Model		Total Energy (MBH)	Fins Per Inch	Rows Deep	Connection Size (in.)	Fluid Flow Rate (GPM)	Fluid Press. Drop (ft wg)
HW12C02H10-70x50-RH		826.9	10	2	2.5	84.6	10.7

Hot Water Unit Unit Details

The RVE will come equipped with the following:

- Aluminum fins
- Copper tubes
- Hand brazed construction
- Galvanized steel casing

Heating Coil Details

Heating Coil Model:	HW12C02H10-70x50-RH
Rows Deep:	2
Fins Per Inch:	10
Face Velocity (ft/min):	555
Total Energy (MBH):	826.9
Entering Dry Bulb (F):	48.0
Leaving Air (F):	104.7
Heat Coil SP (in. wg):	0.145
Entering Fluid (F):	180.0
Leaving Fluid (F):	160.0
Fluid Type:	Water
Glycol (%):	0
Fluid Flow (GPM):	84.6
Fluid PD (ft wg):	10.7
Connection Size (in.):	2.5

GREENHECK
Building Value in Air.

Printed Date: 2/21/2017
Job: WPI Student Project
Mark: Floor 3
Model: RVE-120-74P-30H

ENERGY RECOVERY SUMMER PERFORMANCE

OUTDOOR AIR

Entering Air		Leaving Air	
Dry Bulb (F)	90.8	Dry Bulb (F)	80.9
Wet Bulb (F)	76.2	Wet Bulb (F)	69.0
Specific Humidity (gr/lb)	114	Specific Humidity (gr/lb)	88
Enthalpy (BTU/lb)	39.6	Enthalpy (BTU/lb)	33.0
Leaving Air		**Entering Air**	
Dry Bulb (F)	84.9	Dry Bulb (F)	75.0
Wet Bulb (F)	70.8	Rel. Humidity (%)	50
Specific Humidity (gr/lb)	91	Specific Humidity (gr/lb)	65
Enthalpy (BTU/lb)	34.8	Enthalpy (BTU/lb)	28.1

ENERGY WHEEL

EXHAUST AIR

Design Air Flow Conditions

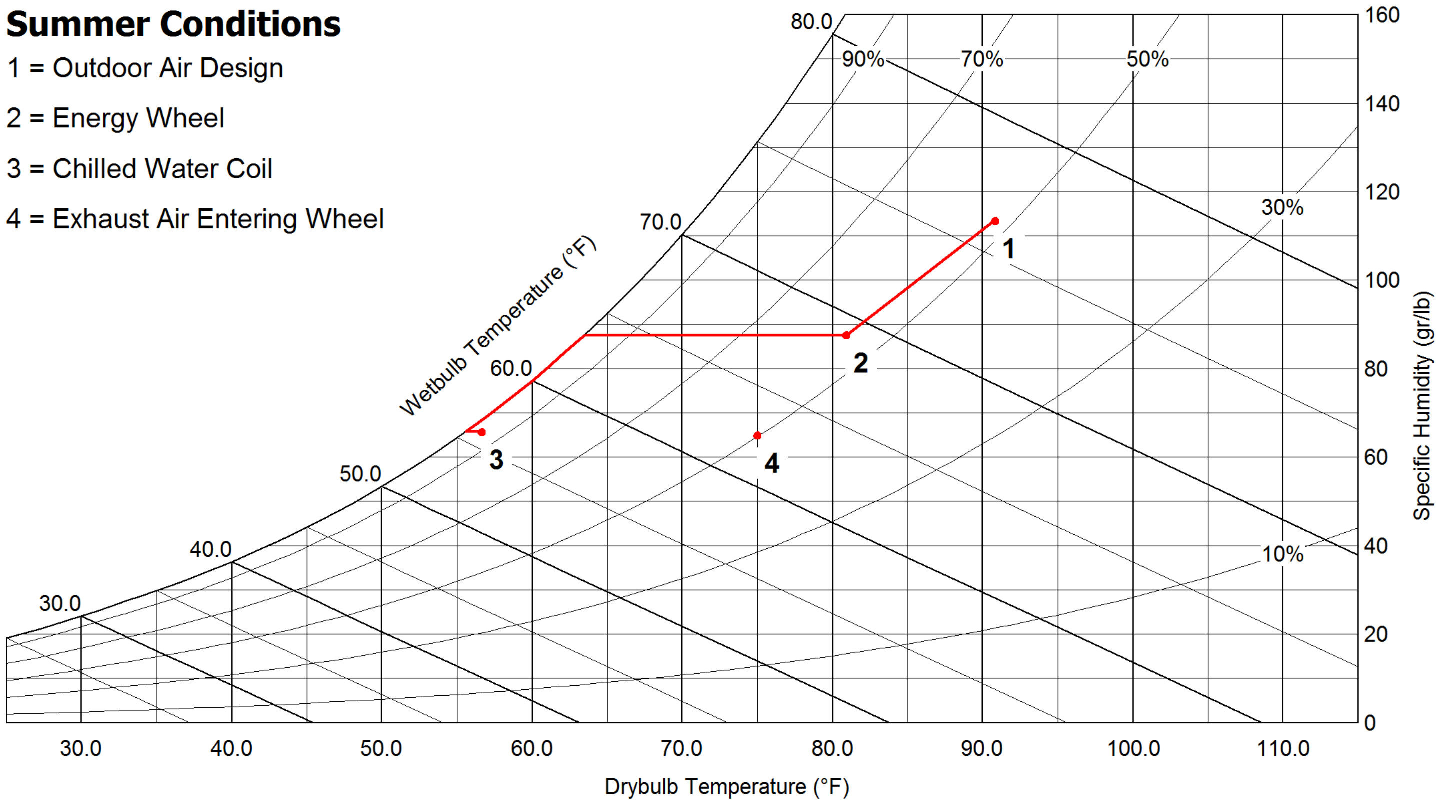
Model	Outdoor Air Volume (CFM)	Outdoor Air Wheel Effectiveness	Exhaust Air Volume (CFM)	Exhaust Air Wheel Effectiveness
RVE-120-74P-30H	13,480	57.8	13,480	57.8

Outdoor Air Cooling Reduction

	(BTU/h)	(tons)
OA Load w/o Energy Recovery	697,590.0	58.13
OA Load with Energy Recovery	297,234.0	24.77
Equipment Reduction tons		33.36

Summer Conditions

1 = Outdoor Air Design
2 = Energy Wheel
3 = Chilled Water Coil
4 = Exhaust Air Entering Wheel



GREENHECK
Building Value in Air.

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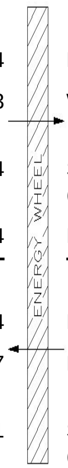
Model: RVE-120-74P-30H

ENERGY RECOVERY WINTER PERFORMANCE

OUTDOOR AIR

Entering Air		Leaving Air	
Dry Bulb (F)	7.4	Dry Bulb (F)	48.0
Wet Bulb (F)	5.3	Wet Bulb (F)	39.9
Specific Humidity (gr/lb)	4	Specific Humidity (gr/lb)	24
Enthalpy (BTU/lb)	2.4	Enthalpy (BTU/lb)	15.4



Leaving Air		Entering Air	
Dry Bulb (F)	31.4	Dry Bulb (F)	72.0
Wet Bulb (F)	29.7	Rel. Humidity (%)	35
Specific Humidity (gr/lb)	21	Specific Humidity (gr/lb)	41
Enthalpy (BTU/lb)	10.6	Enthalpy (BTU/lb)	23.7

EXHAUST AIR

Design Air Flow Conditions

Model	Outdoor Air Volume (CFM)	Outdoor Air Wheel Effectiveness	Exhaust Air Volume (CFM)	Exhaust Air Wheel Effectiveness
RVE-120-74P-30H	13,480	61.2	13,480	61.2

Outdoor Air Heating Reduction

	(BTU/h)
OA Load w/o Energy Recovery	940,473.0
OA Load with Energy Recovery	349,402.0
BTU/h Reduction	591,071.0

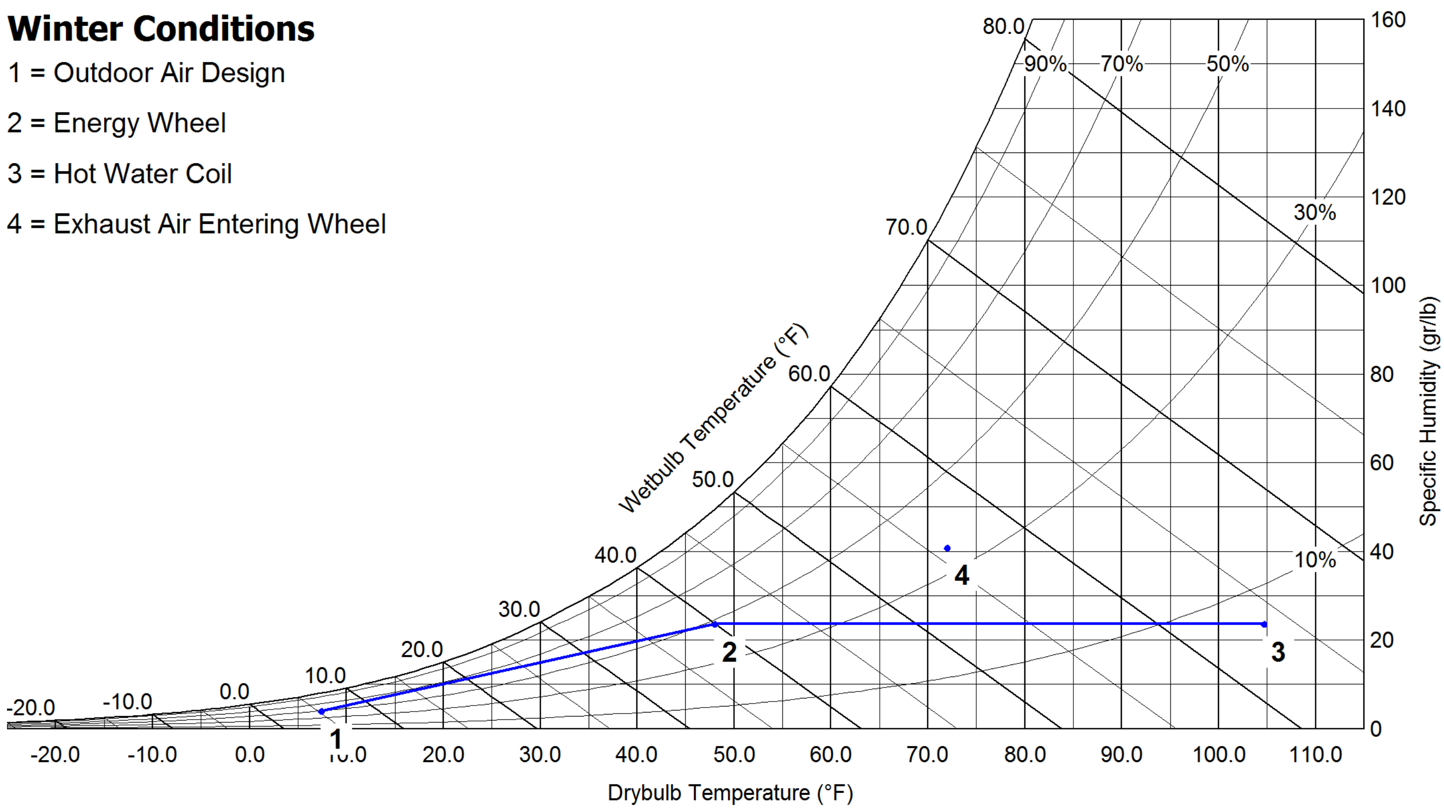
Winter Conditions

1 = Outdoor Air Design

2 = Energy Wheel

3 = Hot Water Coil

4 = Exhaust Air Entering Wheel



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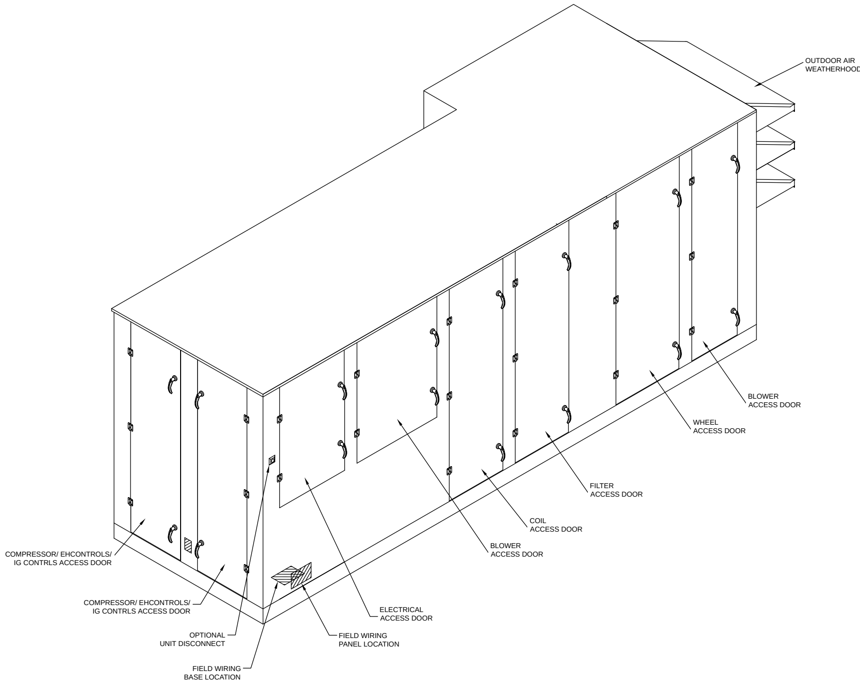
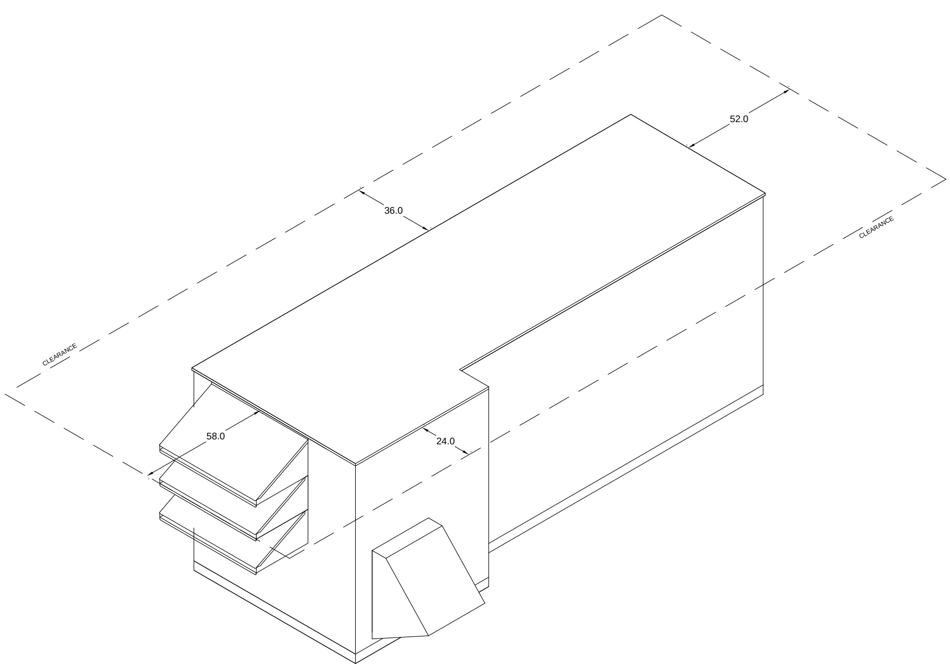
ISOMETRIC DRAWINGS



Back Right Isometric



Front Left Isometric

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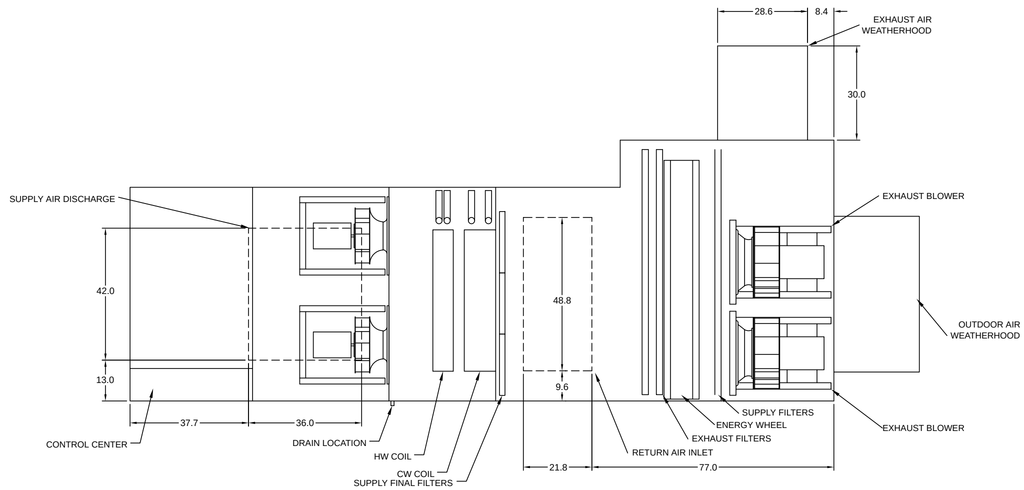
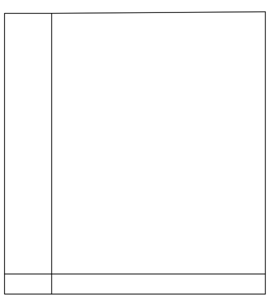
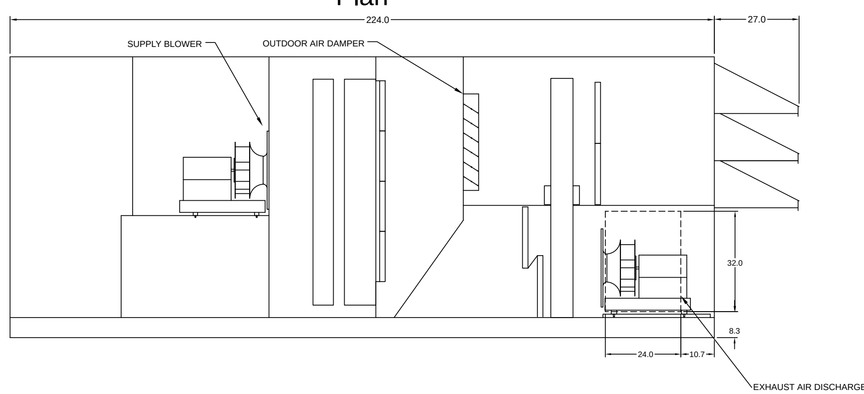
OVERVIEW DRAWINGS



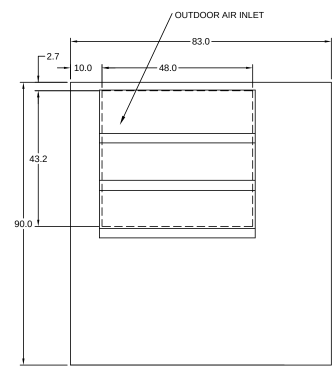
Plan



Left End



Elevation



Right End

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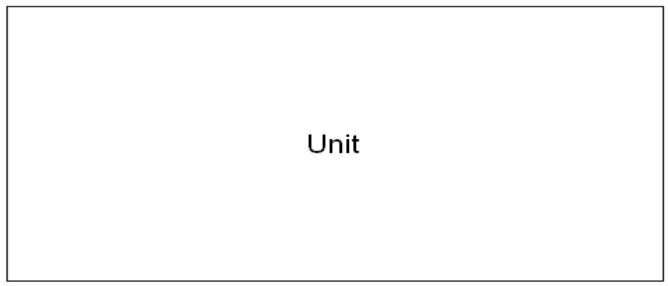
Corner Weights

1,628 lb 2,054 lb



1,022 lb 1,290 lb

Note: Estimated corner weights are shown looking down on unit and the outside air intake will be on the right. Weights are applied at the base of the unit. Images not drawn to scale.

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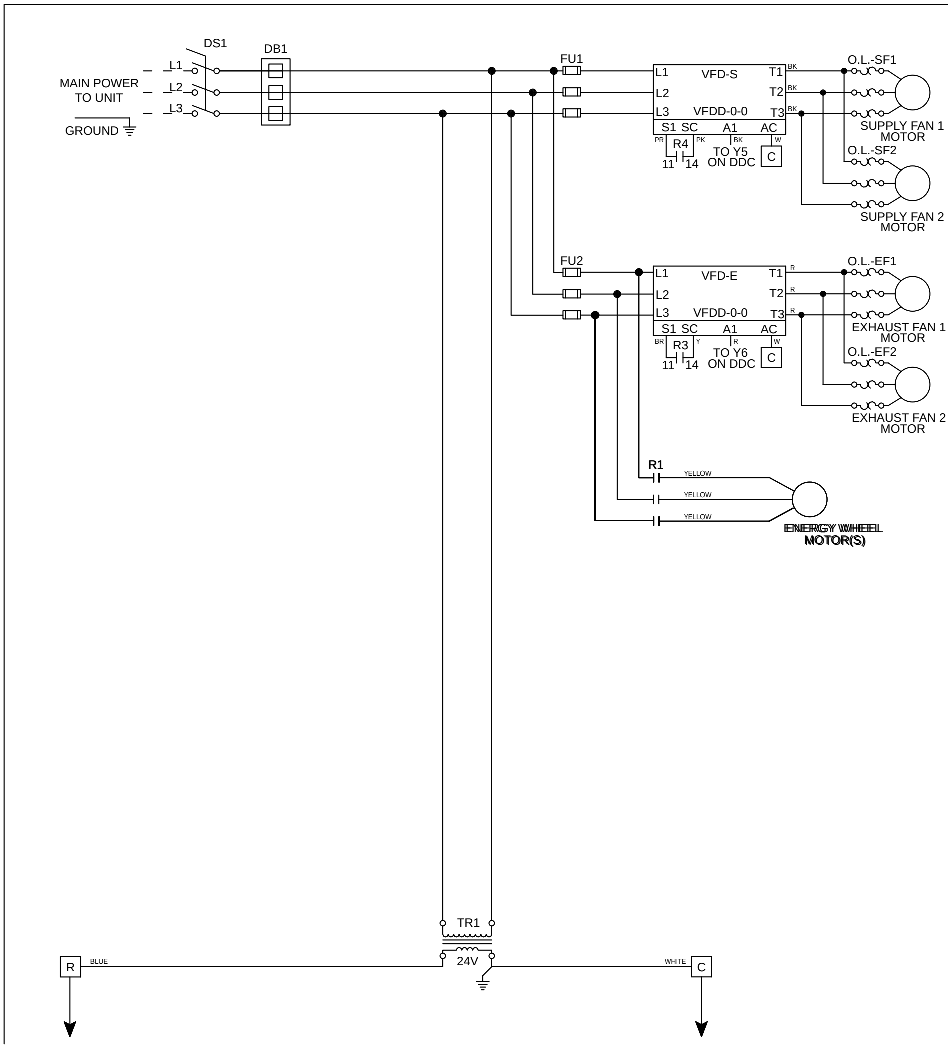
WIRING DIAGRAM



GREENHECK
Building Value in Air.

Wiring Diagram Code:
G53FF1100NACXXXH01

CAUTION

UNIT SHALL BE GROUNDED IN ACCORDANCE WITH N.E.C.
POWER MUST BE OFF WHILE SERVICING.

NOTES

USE COPPER CONDUTORS ONLY
60° C FOR TERMINALS RATED LESS THAN 100 AMPS.
75° C FOR TERMINALS RATED 100 AMPS OR MORE.
FIELD CONTROL WIRING RESISTANCE SHOULD NOT EXCEED 0.75 OHM.
FIELD WIRED – – – – –
FACTORY SUPPLIED AND WIRED ———

WIRE COLOR CODE

BK	BLACK	BL	BLUE	BR	BROWN
GY	GRAY	LT BL	LIGHT BLUE	O	ORANGE
PK	PINK	PR	PURPLE	R	RED
W	WHITE	Y	YELLOW		

LEGEND

DS	DISCONNECT SWITCH
FU#	FUSES
R1	ENERGY WHEEL CONTACTOR
R3	EXHAUST BLOWER VFD RELAY
R4	SUPPLY BLOWER VFD RELAY
TR#	TRANSFORMER
VFD	VARIABLE FREQUENCY DRIVE

Wiring Template: H01

Printed Date: 2/21/2017
Job: WPI Student Project
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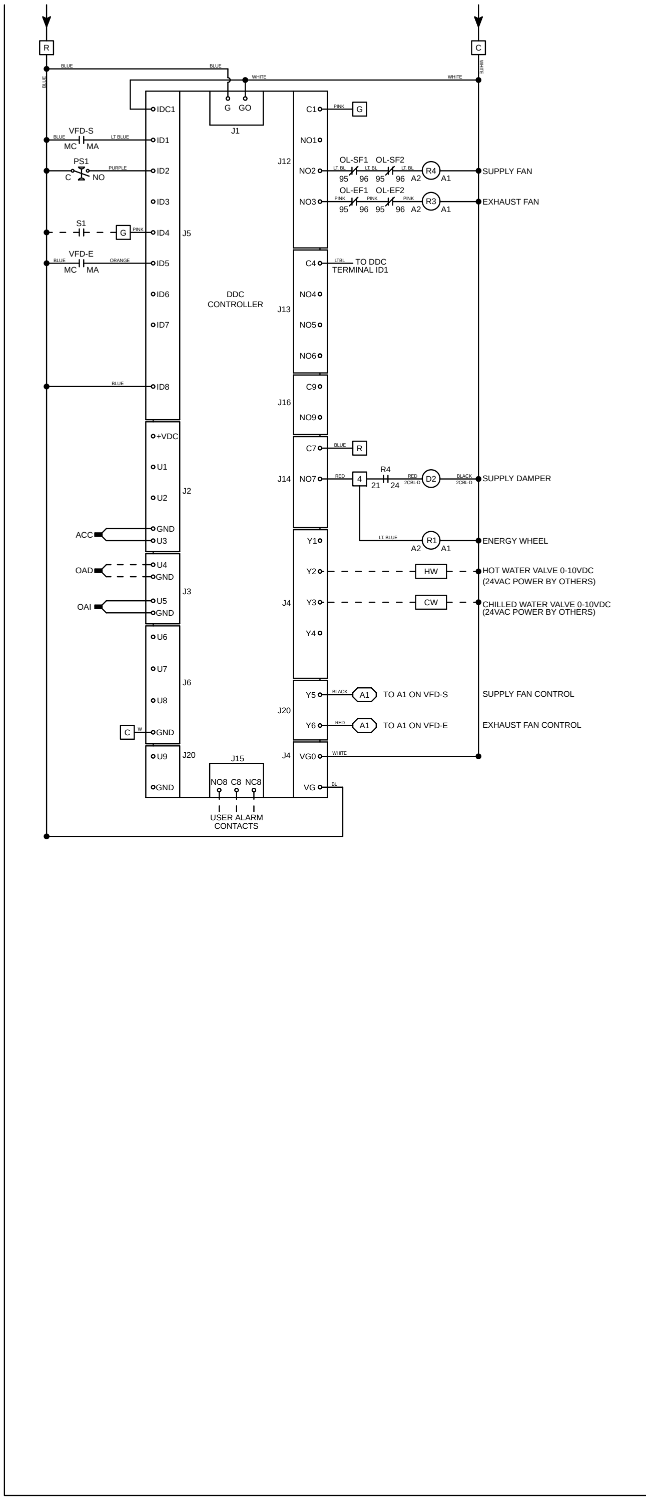
Model: RVE-120-74P-30H

WIRING DIAGRAM 2



GREENHECK
Building Value in Air.

Wiring Diagram Code:

G53FF1100NACXXXG01

CAUTION

UNIT SHALL BE GROUNDED IN ACCORDANCE WITH N.E.C.
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FIELD WIRED - - - - -
FACTORY SUPPLIED AND WIRED ———

WIRE COLOR CODE

BK	BLACK	BL	BLUE	BR	BROWN
GY	GRAY	LT BL	LIGHT BLUE	O	ORANGE
PK	PINK	PR	PURPLE	R	RED
W	WHITE	Y	YELLOW		

LEGEND

ACC AFTER COOLING COIL TEMP
D# DAMPER
PS1 WHEEL FROST PRESSURE SWITCH
R1 ENERGY WHEEL CONTACTOR
R3 EXHAUST BLOWER VFD RELAY
R4 SUPPLY BLOWER VFD RELAY
S1 FAN SWITCH
VFD VARIABLE FREQUENCY DRIVE

DDC Code: Version - TAP v 2.30

GWYCX100XNXN

Wiring Template: G01

GREENHECK
Building Value in Air.

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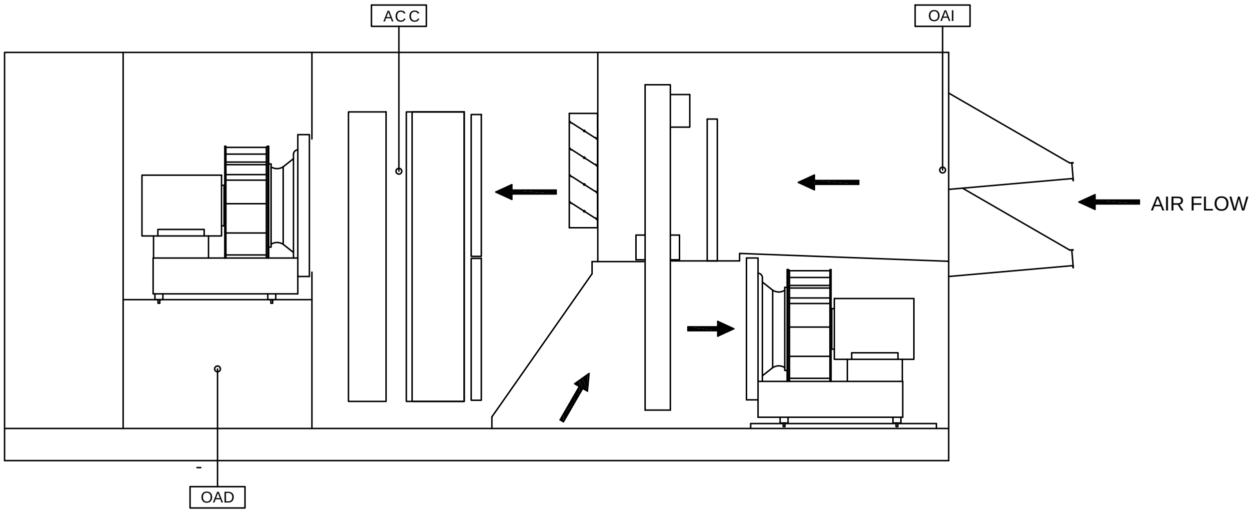
MONITORING POINTS



Item	Description	Type
OAI	Outdoor Air Intake Temperature Sensor	10K Ohm NTC (Carel)
OAD	Outdoor Air Discharge Temperature Sensor	10K Ohm NTC (Carel)
ACC	After Cooling Coil Temperature Sensor	10K Ohm NTC (Carel)

*Shipped loose sensor.

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Building Value in Air.

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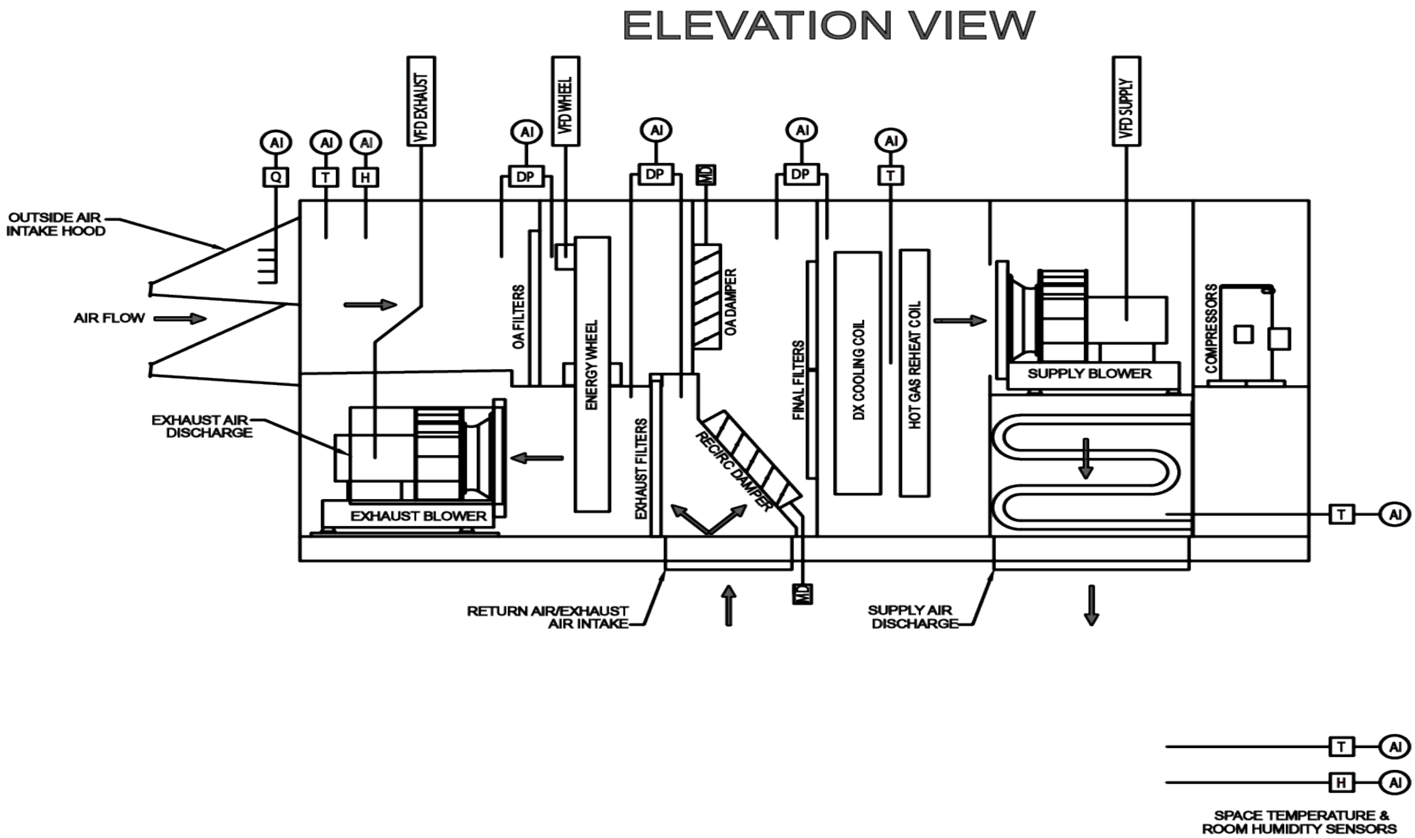
SENSOR LOCATIONS



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Microprocessor Controller Sequence of Operation

MICROPROCESSOR CONTROLLER: Controller shall be provided with required sensors and programming for rooftop unit. Controller shall be factory programmed, mounted and tested. Controller shall have a LCD readout for changing set points and monitoring unit operation.

UNIT START COMMAND (Unit will be enabled to start once a jumper is placed between R to G):

- Factory mounted and wired outdoor air damper actuator is powered
- Exhaust fan starts after a 10 second (adj.) delay.
- Supply fan starts 10 second delay.
- Tempering options and energy wheel option to function as described below.

UNIT STOP COMMAND (OR DE-ENERGIZED):

- Supply fan, exhaust fan, energy wheel and tempering options de-energized.
- Outdoor air damper actuator is spring return close.

OCCUPIED/UNOCCUPIED MODES: Shall be based on a 7-day time clock internal to the controller. The schedule shall be set by the end user. When a user initiates an override input, the controller will switch from unoccupied to occupied mode. The controller will return to the scheduled occupied/unoccupied mode after the override time has expired (60 min, adj.). If internal time clock is disabled, a remote contact or a BMS can control the occupied/ unoccupied mode.

Occupied Mode:

- Damper control per below.
- Energy wheel control per below.
- Exhaust fan ON.
- Supply fan ON.
- Heating per below.
- Cooling per below.

Unoccupied Mode (Unit Off): Unit remains off when in unoccupied mode.

- Supply fan OFF
- Exhaust fan OFF
- Tempering OFF
- Outdoor air damper closed.

Morning Warm-up: One hour prior to occupancy, the controller will reference the temperature differential between the current room temperature and the occupied temperature set point. The controller will then look at the amount of time required from the previous days morning warm up sequence and determine how far in advance the unit has to be started to meet the desired ocupied set point by the time of occupancy.

SUPPLY BLOWER SEQUENCE: The supply blower is provided with a factory mounted variable frequency drive. The supply blower speed will be controlled with the following sequence.

Constant Volume (on/off): The supply blower will operate at a constant speed set point (adj.) during operation.

EXHAUST BLOWER SEQUENCE: The exhaust blower is provided with a factory mounted variable frequency drive. The exhaust blower speed will be controlled with the following sequence.

Constant Volume (on/off): The exhaust blower will operate at a constant speed set point (adj.) during operation.

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COOLING SEQUENCE: The cooling is controlled to maintain the supply temperature set point. The mechanical cooling will be locked out when the outside air is < 55°F - 2°F hysteresis (adj.).

Chilled Water: The controller will modulate a chilled water valve (field provided) to maintain the supply air set point (adj.). Main power to the valve must be provided in field. **Coil Freeze protection must be provided by others in the field!**

DEHUMIDIFICATION SEQUENCE: The cooling is controlled to maintain the cooling-coil set point. The dehumidification sequence will be locked out when the OA is <10°F above the cold-coil set point (adj.).

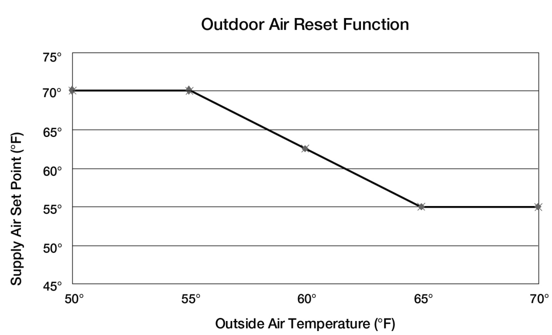
Cold Coil Setpoint Reset Function: The controller will control the cooling to maintain an active set point. The active set point will set to local control (55° F, adj) from the factory and can be field adjusted to the following sequence:

HEATING SEQUENCE: The heating is controlled to maintain the supply temperature set point. The heating will be locked out when the outside air is > 70°F + 2°F hysteresis, (adj.).

Hot Water Coil: The controller will modulate a hot water valve (field provided) to maintain the supply temperature set point (adj.). **Coil Freeze protection must be provided by others in the field!**

SUPPLY SET POINT RESET FUNCTION. The controller will modulate the heating and cooling to maintain an active set point. The active set point will be set to outdoor air reset from the factory and can be field adjusted to the following sequence:

OA Reset (Default): The controller will monitor the outdoor air temperature and adjusts the desired supply temperature set point accordingly. For example, when the outdoor air is below 55 °F, the controller will change the supply set point to 70 °F. If the outdoor air is above 65 °F, the controller will change the supply set point to 55°F. If the outdoor air temperature is between 55°F and 65°F, the supply set point changes according to the outdoor air reset function. A visual representation of this is shown below.



Local: The supply set point will be a constant temperature set from the controller (adj.).

BUILDING FREEZE PROTECTION: If the supply air temperature drops below 35°F (adj.) for 300s (adj.), the controller will de-energize the unit and activate the alarm output.

TEMPERATURE PROTECTION: The controller will enable the supply fan to modulate down to help the unit keep up with heating demand in the event of wheel failure or the unit operating outside design conditions. (This can be enabled under the manufacturer menu in the controller)

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FROST CONTROL: Frost control for the energy wheel is enabled when frost is present on the wheel; based on the outside air temperature and the pressure drop across the wheel. If the outdoor air temperature is below 5°F – 2°F hysteresis, adj. and the differential pressure across the wheel is about 1.5", adj. frost control will enable.

Timed Exhaust: When frosting is occurring, the supply blower is cycled (30 min. ON / 5 min. OFF, adj.) to allow the warm exhaust air to defrost the wheel. Once either the pressure drop decreases below the pressure switch set point, or the outdoor air temperature increases above the temperature set point, the unit will resume normal operation.

ALARMS INDICATION: The controller will display alarms and have one digital output for remote indication of an alarm condition. Possible alarms include:

Dirty Wheel Alarm: The controller monitors pressure across the wheel and sends an alarm in the case of an increased pressure drop.

Supply and Exhaust Air Alarm: The controller monitors the proving switch on each blower and sends an alarm in the case of either blower proving switch not engaging for 30s (adj.).

Temperature Sensor Alarm: The controller sends an alarm in the case of a failed air temperature sensor.

Accessories: The following accessories will be included with the unit to expand the functionality or usability of the controller.

Unit Warranty

Limited Warranty

Greenheck warrants this equipment to be free from defects in material and workmanship for a period of 1 year(s) from the purchase date. The energy recovery wheel is warranted to be free from defects in material and workmanship for a period of five years from the purchase date. Any component which proves defective during the warranty period will be repaired, or replaced, at Greenheck's sole option when returned to our factory, transportation prepaid.

The warranty does not include labor costs associated with troubleshooting, removal, or installation. Greenheck will not be liable for any consequential, punitive, or incidental damages resulting from use, repair, or operation of any Greenheck product.

This warranty is exclusive, and is in lieu of all other warranties, whether written, oral or implied, including the warranty of merchantability and the warranty of fitness for a particular purpose.

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Mark: Floor 4
Model: RVE-80-58P-30H

RVE-80-58P-30H

CONSTRUCTION FEATURES AND ACCESSORIES

Unit Overview

Model	Supply (CFM)	Outside Air (CFM)	Recirc (CFM)	Exhaust (CFM)	Heating	Cooling	Electrical V/C/P
RVE-80-58P-30H	7,770	7,770	0	7,770	Hot Water	Chilled Water	208/60/3

Features

- Exterior housing constructed of galvanized steel
- Energy recovery cassette with a desiccant wheel
- Direct-drive backward inclined plenum blowers with factory mounted VFDs
- Ball bearing motors
- Corrosion resistant fasteners
- Internally lined with galvanized steel metal creating a double wall
- Insulated with 2 in. 1.5# R8 density insulation
- Internally mounted control center with motor starters, 24 VAC control transformer(s), control circuit fusing
- Energy Wheel Motor: 1/6 HP
- Stainless steel condensate drain pan and connection.

Options and Accessories

- UL\cUL1995
- Frost Control: Timed Exhaust
- Weatherhood: Downturned Hood
- Outdoor Air Filters - MERV 8, 7-16x20x2
- Exhaust Air Filters - MERV 8, 7-16x20x2
- Supply Filters - 2" Pleated MERV 8, 6-20x25x2
- Roof Curbs - GKD-62.65/172.83-G14"
- Outdoor Air Dampers - Motorized Low Leakage
- Painted Exterior - Permatector Concrete Gray (RAL 7023)
- Microprocessor Controls
- Supply Fan Controls - Constant Volume (on/off)
- Exhaust Fan Controls - Constant Volume
- Unit Disconnect - Mounted By Factory
- Short-circuit current - 5kA
- Exhaust Discharge Gravity Backdraft Damper

Note: Unit is provided with factory mounted and wired disconnect switch.

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Building Value in Air.

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PERFORMANCE AND SPECIFICATIONS

Description/Arrangement

Model	Qty	Unit Weight (lb)	Outdoor Air Discharge	Outdoor Air Intake	Exhaust Air Discharge	Return Air Intake
RVE-80-58P-30H	2	3,752	Bottom	End	Side	Bottom

Design Conditions

Elevation (ft)	Summer DB (F)	Summer WB (F)	Winter DB (F)
30	91	76	7

Air Performance

Type	Volume (CFM)	External SP (in. wg)	Total SP (in. wg)	RPM	Operating Power (hp)	Motor Qty/Size (hp)	Size (in.)/ Type
Supply	7,770	1	3.23	1648	5.75	Qty 1 (7-1/2)	22/Plenum
ExhaustNormal	7,770	1	2.844	2008	5.69	Qty 1 (7-1/2)	20/Plenum

Electrical/Motor Specifications

V/C/P	Unit MCA (amps)	Unit MOP (amps)	Enclosure	Supply Motor RPM	Supply Efficiency	Exhaust Motor RPM	Exhaust Efficiency
208/60/3	55.7	70	ODP	1750	PE	1750	PE

Heating/Cooling Specifications

Heating Type	Entering Air Temp. (F)	Leaving Air Temp. (F)	Fluid Type	Face Velocity (ft/min)	Air Pressure Drop (in. wg)	Entering Fluid Temp. (F)	Leaving Fluid Temp. (F):
Hot Water	47.0	111.2	Water	407	0.091	180.0	160.0
HW Coil Model		Total Energy (MBH)	Fins Per Inch	Rows Deep	Connection Size (in.)	Fluid Flow Rate (GPM)	Fluid Press. Drop (ft wg)
HW12C02H10-55x50-RH		539.7	10	2	2	55.2	6.2

Cooling Type	Entering Air (F)		Leaving Air (F)		Capacity (MBH)		Fluid Temps (F)	
	Dry-bulb	Wet-bulb	Dry-bulb	Wet-bulb	Total	Sensible	Entering	Leaving
Chilled Water	81.0	68.6	54.0	53.6	365.8	230.5	45.0	55.0
CW Coil Model		Fins Per Inch	Rows Deep	Fluid Type	Face Vel. (ft/min):	Air Press. Drop (in. wg):	Fluid Flow (GPM)	Fluid Press. Drop (ft wg)
CW12C06T10-55x50-RH		10	6	Water	407	0.463	72.9	9.1

Sound Performance in Accordance with AMCA

Fan	Sound Power by Octave Band								Lwa	dBA	Sones
	62.5	125	250	500	1000	2000	4000	8000			
Supply	85	86	91	88	86	83	77	73	91	79	29
Exhaust Normal	81	80	86	85	80	79	74	70	87	75	23

Unit Pressure Drop (in. wg)

Air Stream	Weatherhood	Damper Section	Filter Section	Cooling Section	Heating Section
Supply	0.121	0.121	0.241	0.463	0.091
Exhaust	0.11	0	0.121	N/A	N/A

Note: The unit base line performance incorporates the pressure drop of the energy wheel.

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Note: Filter pressure drop is based off of clean filters.

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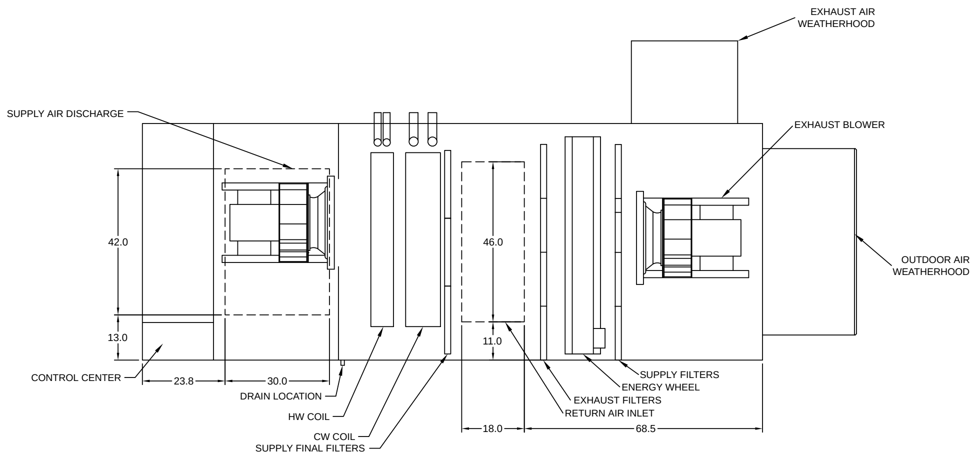
RADIATED SOUND

Position C

Position D



Position B

Plan

Position A

Position E = Top of Unit

RVE-80: Supply Air Flow Nominal, Largest Tonnage Condensing Section Available, PDX units only

Free Field Plane	Octave Band (Sound Power Lw)								Lw	LwA
	1	2	3	4	5	6	7	8		
A	99	92	94	92	89	84	74	68	102	94
B	89	85	87	84	81	75	67	59	93	86
C	91	87	87	83	80	75	66	56	94	85
D	87	88	87	83	82	78	68	59	93	86
E	104	94	84	91	88	83	76	69	105	92

AMCA 320-07 - Laboratory Methods of Sound Testing of Fans Using Sound Intensity
Tests conducted in accordance with this standard.
Free field measurement plane created 1 foot from unit on all sides and top.
Sound Intensity measured in Watts/m^2.
Sound data converted to Sound Power (Lw) for the chart above.
A-Weighted Sound Power was determined using AMCA Standard 301-90 Clause 9.1.

GREENHECK
Building Value in Air.

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Model: RVE-80-58P-30H

COOLING PERFORMANCE

Chilled Water Cooling

Cooling Type	Entering Air (F)		Leaving Air (F)		Capacity (MBH)		Fluid Temps (F)	
	Dry-bulb	Wet-bulb	Dry-bulb	Wet-bulb	Total	Sensible	Entering	Leaving
Chilled Water	81.0	68.6	54.0	53.6	365.8	230.5	45.0	55.0

CW Coil Model	Fins Per Inch	Rows Deep	Fluid Type	Face Vel. (ft/min):	Air Press. Drop (in. wg):	Fluid Flow (GPM)	Fluid Press. Drop (ft wg)
CW12C06T10-55x50-RH	10	6	Water	407	0.463	72.9	9.1

Chilled Water Unit Details

The RVE will come equipped with the following:
- Aluminum fins
- Copper tubes
- Hand brazed construction
- Galvanized steel casing

Chilled Water Coil Details

Cooling Coil Model:	CW12C06T10-55x50-RH
Rows Deep:	6
Fins Per Inch:	10
Face Velocity (ft/min):	407
Total Energy (MBH):	365.8
Sensible Capacity (MBH):	230.5
Entering Dry Bulb (F):	81.0
Entering Wet Bulb (F):	68.6
Leaving Dry Bulb (F):	54.0
Leaving Wet Bulb (F):	53.6
Cool Coil SP (in. wg):	0.463
Entering Fluid (F):	45.0
Leaving Fluid (F):	55.0
Fluid Type:	Water
Glycol (%):	0
Fluid Flow (GPM):	72.9
Fluid PD (ft wg):	9.1
Connection Size (in.):	2.5

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Model: RVE-80-58P-30H

HEATING PERFORMANCE

Hot Water Heating

Heating Type	Entering Air Temp. (F)	Leaving Air Temp. (F)	Fluid Type	Face Velocity (ft/min)	Air Pressure Drop (in. wg)	Entering Fluid Temp. (F)	Leaving Fluid Temp. (F):
Hot Water	47.0	111.2	Water	407	0.091	180.0	160.0
HW Coil Model		Total Energy (MBH)	Fins Per Inch	Rows Deep	Connection Size (in.)	Fluid Flow Rate (GPM)	Fluid Press. Drop (ft wg)
HW12C02H10-55x50-RH		539.7	10	2	2	55.2	6.2

Hot Water Unit Unit Details

The RVE will come equipped with the following:
- Aluminum fins
- Copper tubes
- Hand brazed construction
- Galvanized steel casing

Heating Coil Details

Heating Coil Model:	HW12C02H10-55x50-RH
Rows Deep:	2
Fins Per Inch:	10
Face Velocity (ft/min):	407
Total Energy (MBH):	539.7
Entering Dry Bulb (F):	47.0
Leaving Air (F):	111.2
Heat Coil SP (in. wg):	0.091
Entering Fluid (F):	180.0
Leaving Fluid (F):	160.0
Fluid Type:	Water
Glycol (%):	0
Fluid Flow (GPM):	55.2
Fluid PD (ft wg):	6.2
Connection Size (in.):	2

GREENHECK
Building Value in Air.

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ENERGY RECOVERY SUMMER PERFORMANCE

OUTDOOR AIR

Entering Air		Leaving Air	
Dry Bulb (F)	90.8	Dry Bulb (F)	81.0
Wet Bulb (F)	76.2	Wet Bulb (F)	68.6
Specific Humidity (gr/lb)	114	Specific Humidity (gr/lb)	85
Enthalpy (BTU/lb)	39.6	Enthalpy (BTU/lb)	32.6
Leaving Air		**Entering Air**	
Dry Bulb (F)	84.8	Dry Bulb (F)	75.0
Wet Bulb (F)	71.1	Rel. Humidity (%)	50
Specific Humidity (gr/lb)	93	Specific Humidity (gr/lb)	65
Enthalpy (BTU/lb)	35.1	Enthalpy (BTU/lb)	28.1

ENERGY WHEEL

EXHAUST AIR

Design Air Flow Conditions

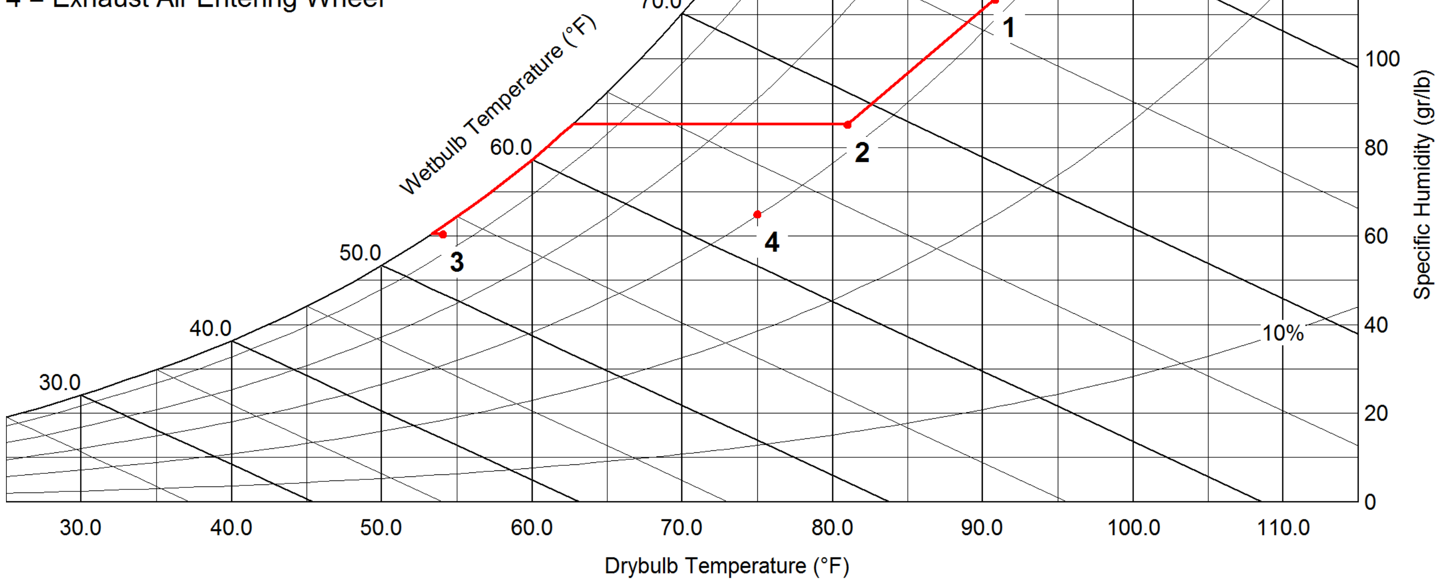
Model	Outdoor Air Volume (CFM)	Outdoor Air Wheel Effectiveness	Exhaust Air Volume (CFM)	Exhaust Air Wheel Effectiveness
RVE-80-58P-30H	7,770	60.9	7,770	60.9

Outdoor Air Cooling Reduction

	(BTU/h)	(tons)
OA Load w/o Energy Recovery	402,098.0	33.51
OA Load with Energy Recovery	157,342.0	13.11
Equipment Reduction tons		20.40

Summer Conditions

1 = Outdoor Air Design
2 = Energy Wheel
3 = Chilled Water Coil
4 = Exhaust Air Entering Wheel



GREENHECK
Building Value in Air.

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ENERGY RECOVERY WINTER PERFORMANCE

OUTDOOR AIR

Entering Air		Leaving Air	
Dry Bulb (F)	7.4	Dry Bulb (F)	47.4
Wet Bulb (F)	5.3	Wet Bulb (F)	40.2
Specific Humidity (gr/lb)	4	Specific Humidity (gr/lb)	26
Enthalpy (BTU/lb)	2.4	Enthalpy (BTU/lb)	15.6
Leaving Air		**Entering Air**	
Dry Bulb (F)	32.0	Dry Bulb (F)	72.0
Wet Bulb (F)	29.4	Rel. Humidity (%)	35
Specific Humidity (gr/lb)	20	Specific Humidity (gr/lb)	41
Enthalpy (BTU/lb)	10.4	Enthalpy (BTU/lb)	23.7

ENERGY WHEEL

EXHAUST AIR

Design Air Flow Conditions

Model	Outdoor Air Volume (CFM)	Outdoor Air Wheel Effectiveness	Exhaust Air Volume (CFM)	Exhaust Air Wheel Effectiveness
RVE-80-58P-30H	7,770	62.2	7,770	62.2

Outdoor Air Heating Reduction

	(BTU/h)
OA Load w/o Energy Recovery	542,097.0
OA Load with Energy Recovery	206,433.0
BTU/h Reduction	335,664.0

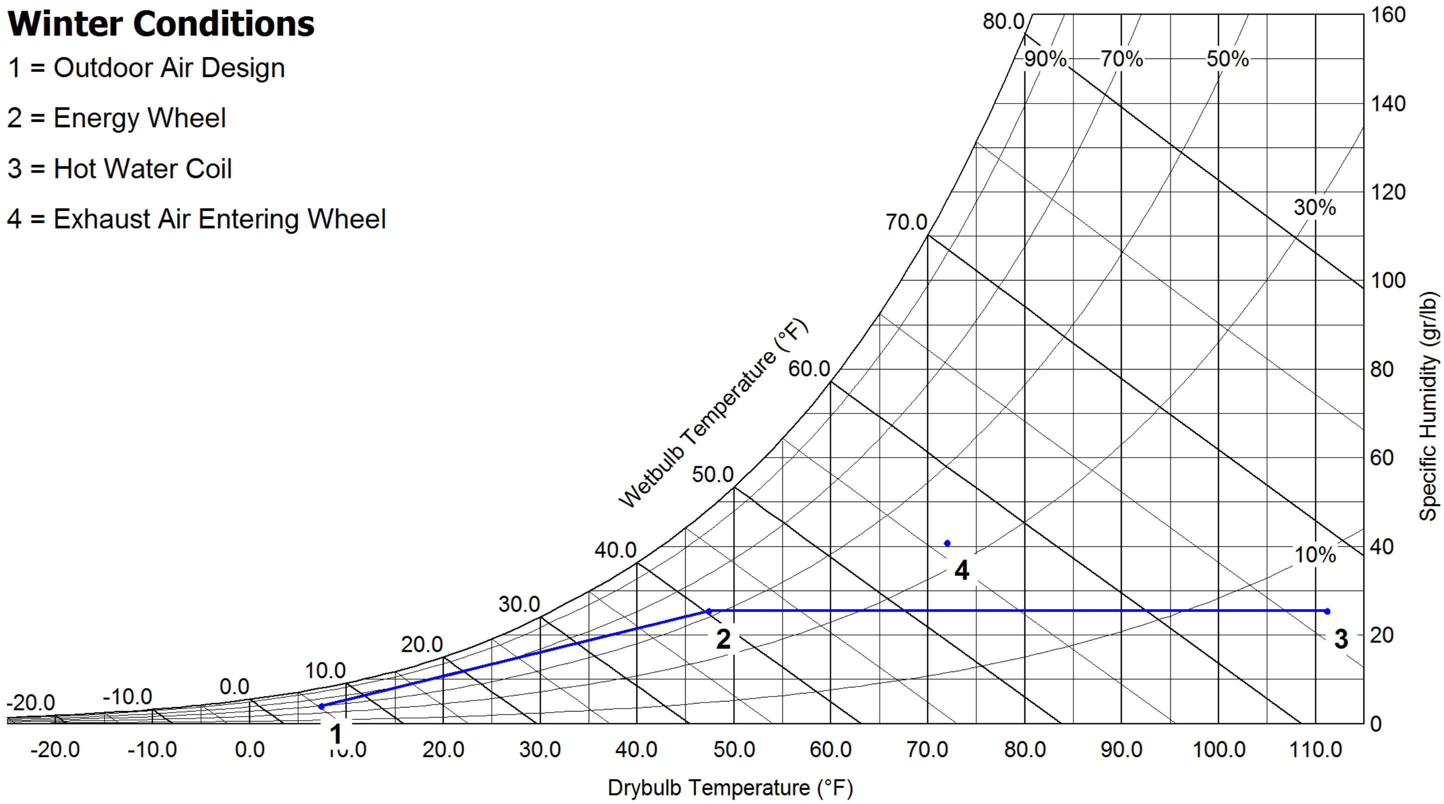
Winter Conditions

1 = Outdoor Air Design

2 = Energy Wheel

3 = Hot Water Coil

4 = Exhaust Air Entering Wheel



GREENHECK
Building Value in Air.

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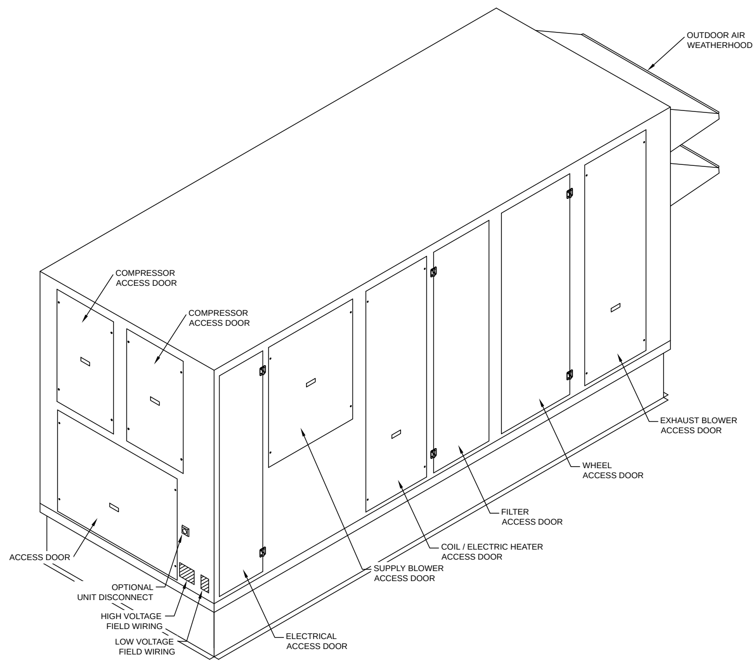
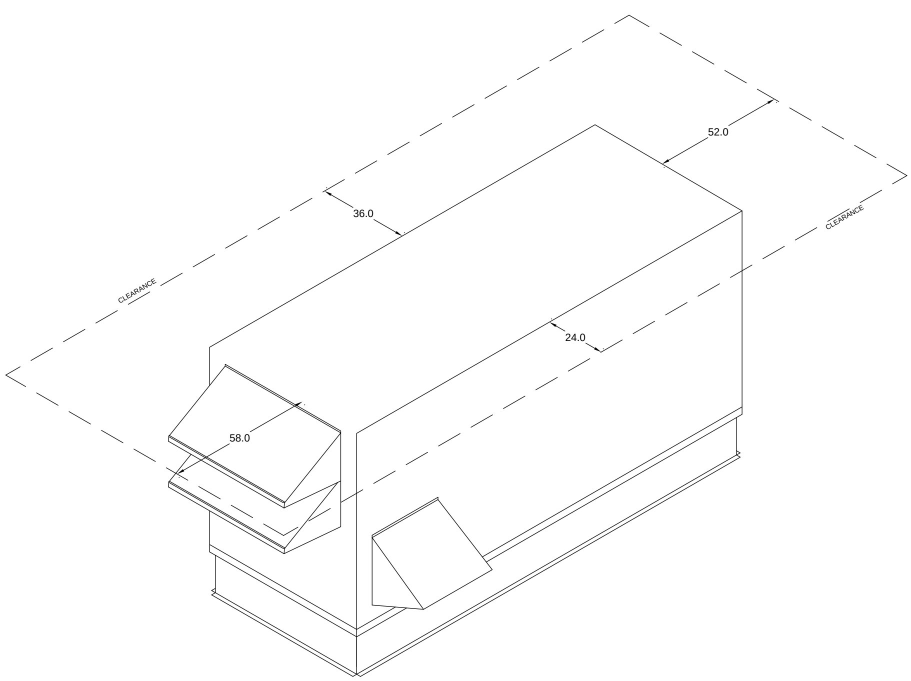
ISOMETRIC DRAWINGS



Back Right Isometric



Front Left Isometric

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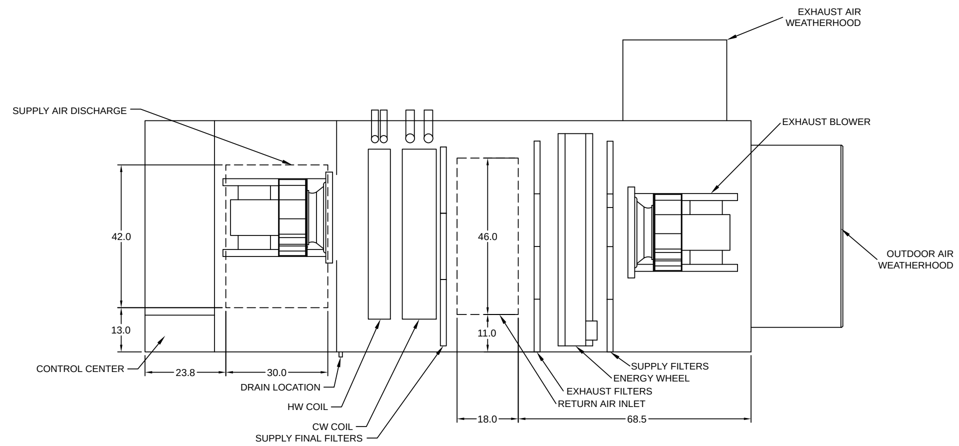
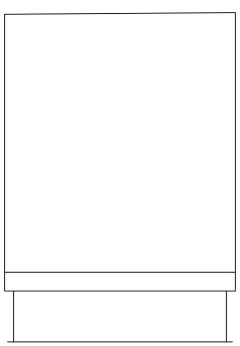
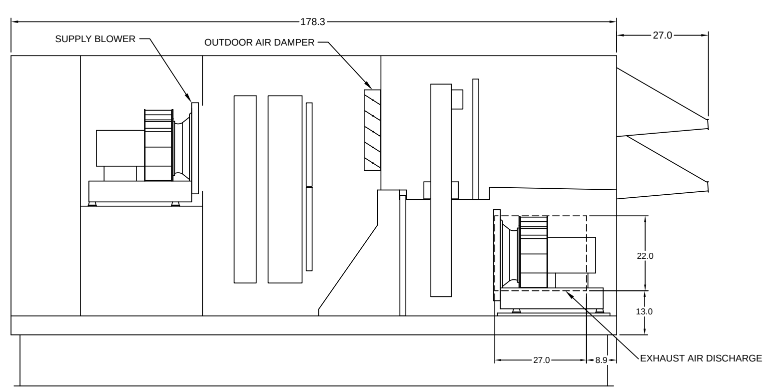
OVERVIEW DRAWINGS



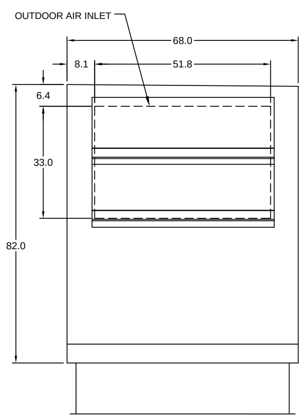
Plan



Left End



Elevation



Right End

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Building Value in Air.

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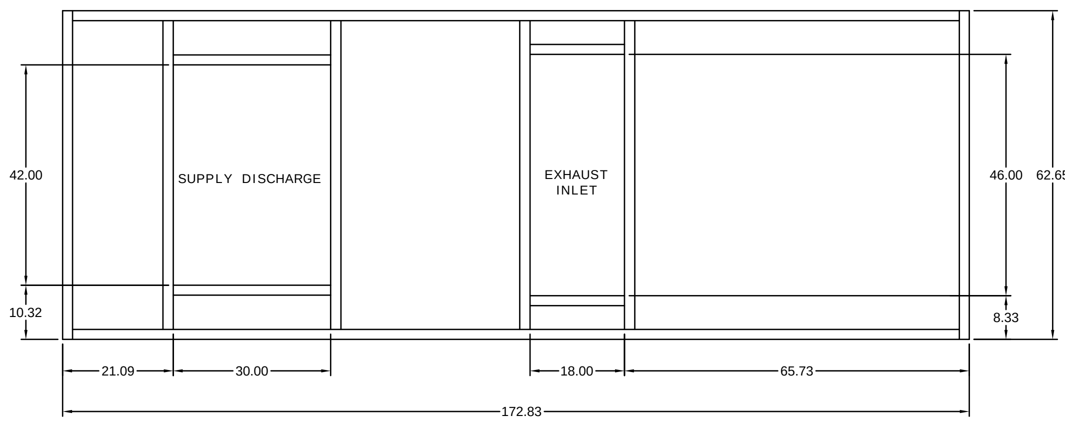
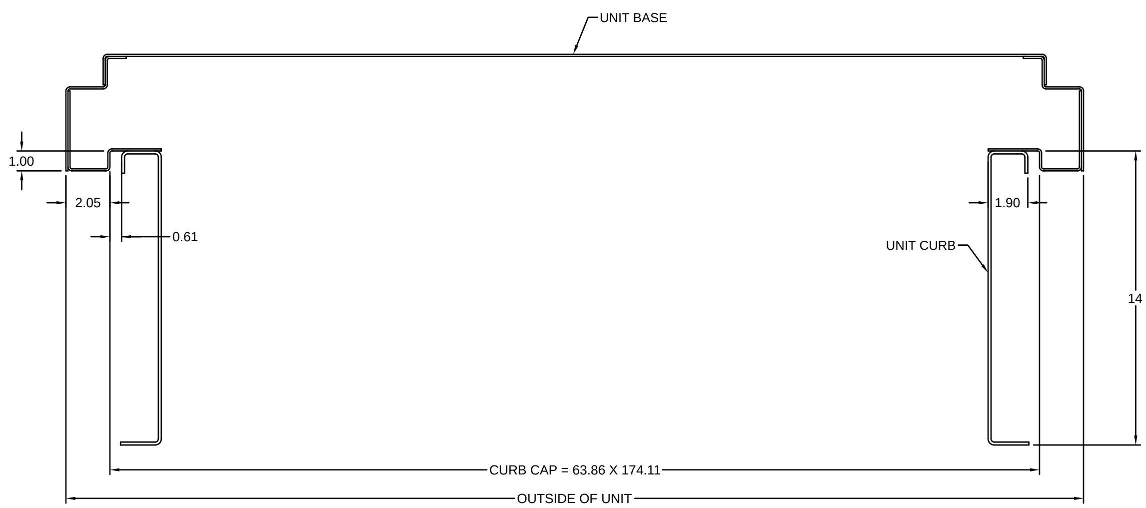
FOOTPRINT DRAWINGS

Top View of Curb



Cross-Section View of Unit on Curb



NOTES: All dimensions shown are in units of in.'s
If unit is selected with side or end discharge/return, there will not be bottom connections supplied with the curb.

Curb Weight: 304 lb

GREENHECK
Building Value in Air.

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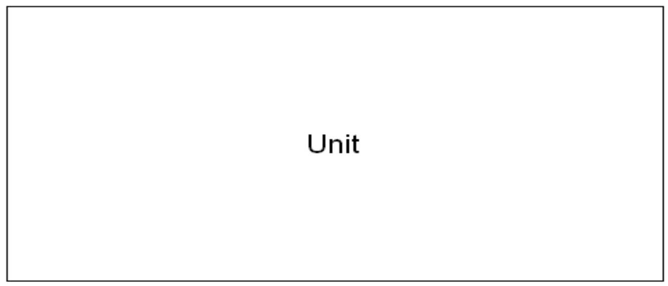
Corner Weights

905 lb 938 lb



938 lb 972 lb

Note: Estimated corner weights are shown looking down on unit and the outside air intake will be on the right. Weights are applied at the base of the unit. Images not drawn to scale.

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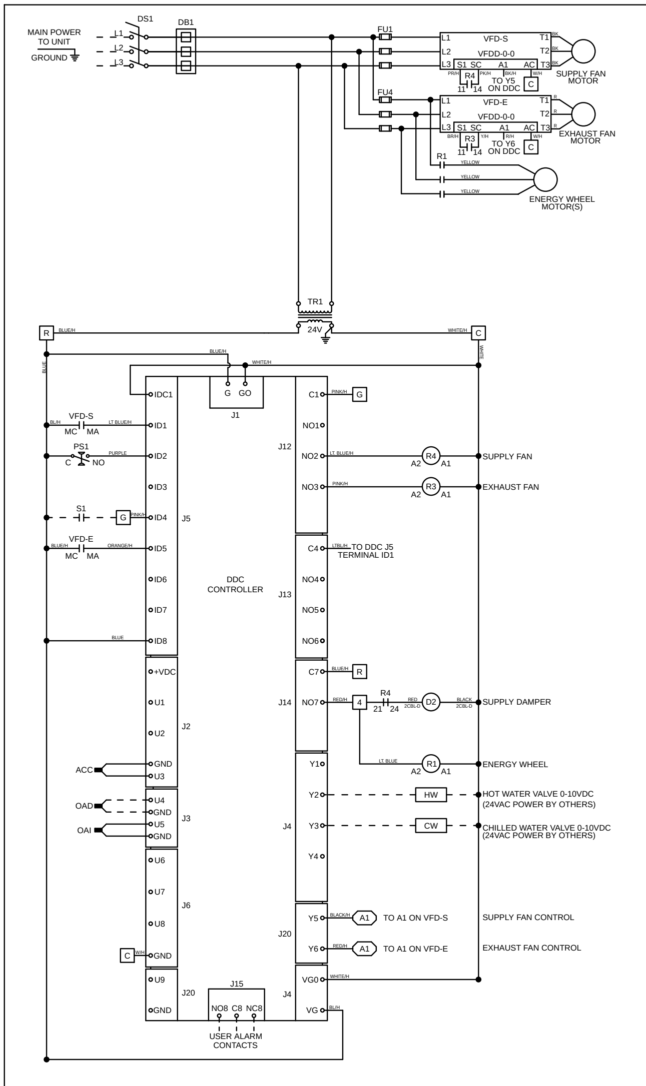
WIRING DIAGRAM



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Building Value in Air.

Wiring Diagram Code:

G53FF1100NACXXXF13

CAUTION

UNIT SHALL BE GROUNDED IN ACCORDANCE WITH N.E.C.
POWER MUST BE OFF WHILE SERVICING.

NOTES

USE COPPER CONDUCTORS ONLY
60° C FOR TERMINALS RATED LESS THAN 100 AMPS.
75° C FOR TERMINALS RATED 100 AMPS OR MORE.

FIELD CONTROL WIRING RESISTANCE SHOULD NOT EXCEED 0.75 OHM.

FIELD WIRED – – – – –
FACTORY SUPPLIED AND WIRED ———

WIRE COLOR CODE

BK	BLACK	BL	BLUE	BR	BROWN
GY	GRAY	LT BL	LIGHT BLUE	O	ORANGE
PK	PINK	PR	PURPLE	R	RED
W	WHITE	Y	YELLOW		

LEGEND

ACC	AFTER COOLING COIL TEMP
D#	DAMPER
DB#	POWER DISTRIBUTION BLOCK
DS	DISCONNECT SWITCH
FU#	FUSES
OAD	OUTDOOR AIR DISHCHARGE TEMP
OAI	OUTDOOR AIR INLET TEMP
PS1	WHEEL FROST PRESSURE SWITCH
R1	ENERGY WHEEL CONTACTOR
R3	EXHAUST BLOWER VFD RELAY
R4	SUPPLY BLOWER VFD RELAY
S1	FAN SWITCH
TR#	TRANSFORMER
VFD	VARIABLE FREQUENCY DRIVE

DDC Code: Version - TAP v 2.40

GWCCX100 XNXN

Wiring Template: F13

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Building Value in Air.

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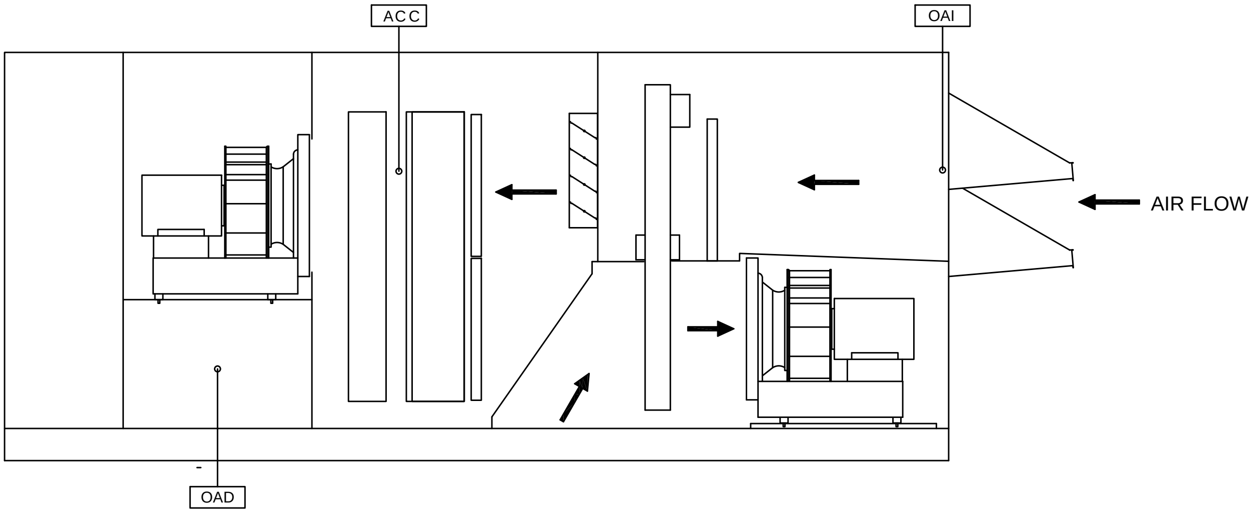
MONITORING POINTS



Item	Description	Type
OAI	Outdoor Air Intake Temperature Sensor	10K Ohm NTC (Carel)
OAD	Outdoor Air Discharge Temperature Sensor	10K Ohm NTC (Carel)
ACC	After Cooling Coil Temperature Sensor	10K Ohm NTC (Carel)

*Shipped loose sensor.

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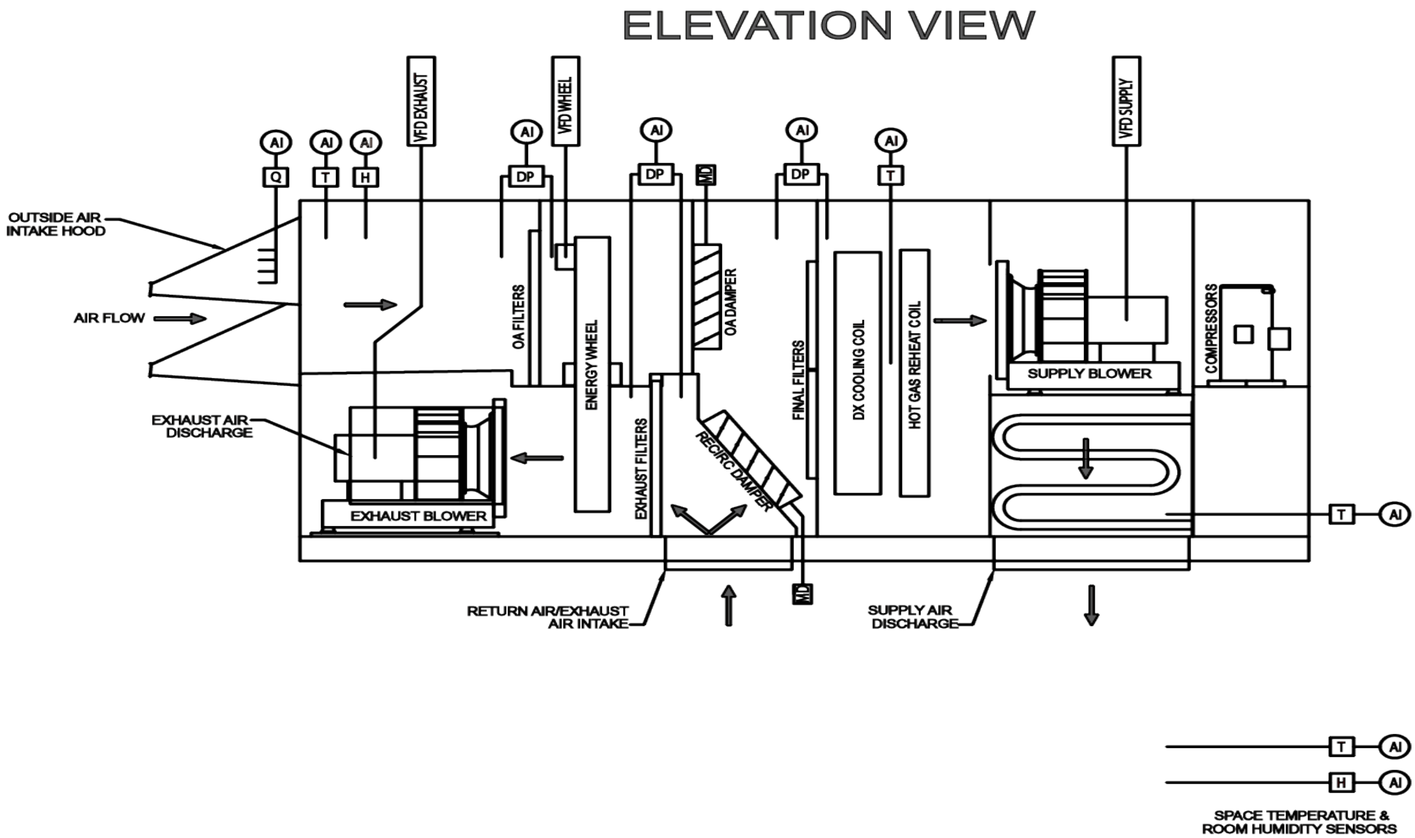
SENSOR LOCATIONS



GREENHECK
Building Value in Air.

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Microprocessor Controller Sequence of Operation

MICROPROCESSOR CONTROLLER: Controller shall be provided with required sensors and programming for rooftop unit. Controller shall be factory programmed, mounted and tested. Controller shall have a LCD readout for changing set points and monitoring unit operation.

UNIT START COMMAND (Unit will be enabled to start once a jumper is placed between R to G):
- Factory mounted and wired outdoor air damper actuator is powered
- Exhaust fan starts after a 10 second (adj.) delay.
- Supply fan starts 10 second delay.
- Tempering options and energy wheel option to function as described below.

UNIT STOP COMMAND (OR DE-ENERGIZED):
- Supply fan, exhaust fan, energy wheel and tempering options de-energized.
- Outdoor air damper actuator is spring return close.

OCCUPIED/UNOCCUPIED MODES: Shall be based on a 7-day time clock internal to the controller. The schedule shall be set by the end user. When a user initiates an override input, the controller will switch from unoccupied to occupied mode. The controller will return to the scheduled occupied/unoccupied mode after the override time has expired (60 min, adj.). If internal time clock is disabled, a remote contact or a BMS can control the occupied/ unoccupied mode.

Occupied Mode:
- Damper control per below.
- Energy wheel control per below.
- Exhaust fan ON.
- Supply fan ON.
- Heating per below.
- Cooling per below.

Unoccupied Mode (Unit Off): Unit remains off when in unoccupied mode.
- Supply fan OFF
- Exhaust fan OFF
- Tempering OFF
- Outdoor air damper closed.

Morning Warm-up: One hour prior to occupancy, the controller will reference the temperature differential between the current room temperature and the occupied temperature set point. The controller will then look at the amount of time required from the previous days morning warm up sequence and determine how far in advance the unit has to be started to meet the desired ocupied set point by the time of occupancy.

SUPPLY BLOWER SEQUENCE: The supply blower is provided with a factory mounted variable frequency drive. The supply blower speed will be controlled with the following sequence.

Constant Volume (on/off): The supply blower will operate at a constant speed set point (adj.) during operation.

EXHAUST BLOWER SEQUENCE: The exhaust blower is provided with a factory mounted variable frequency drive. The exhaust blower speed will be controlled with the following sequence.

Constant Volume (on/off): The exhaust blower will operate at a constant speed set point (adj.) during operation.

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COOLING SEQUENCE: The cooling is controlled to maintain the supply temperature set point. The mechanical cooling will be locked out when the outside air is < 55°F - 2°F hysteresis (adj.).

Chilled Water: The controller will modulate a chilled water valve (field provided) to maintain the supply air set point (adj.). Main power to the valve must be provided in field. **Coil Freeze protection must be provided by others in the field!**

DEHUMIDIFICATION SEQUENCE: The cooling is controlled to maintain the cooling-coil set point. The dehumidification sequence will be locked out when the OA is <10°F above the cold-coil set point (adj.).

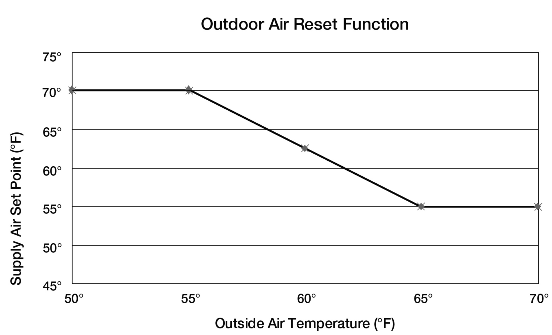
Cold Coil Setpoint Reset Function: The controller will control the cooling to maintain an active set point. The active set point will set to local control (55° F, adj) from the factory and can be field adjusted to the following sequence:

HEATING SEQUENCE: The heating is controlled to maintain the supply temperature set point. The heating will be locked out when the outside air is > 70°F + 2°F hysteresis, (adj.).

Hot Water Coil: The controller will modulate a hot water valve (field provided) to maintain the supply temperature set point (adj.). **Coil Freeze protection must be provided by others in the field!**

SUPPLY SET POINT RESET FUNCTION. The controller will modulate the heating and cooling to maintain an active set point. The active set point will be set to outdoor air reset from the factory and can be field adjusted to the following sequence:

OA Reset (Default): The controller will monitor the outdoor air temperature and adjusts the desired supply temperature set point accordingly. For example, when the outdoor air is below 55 °F, the controller will change the supply set point to 70 °F. If the outdoor air is above 65 °F, the controller will change the supply set point to 55°F. If the outdoor air temperature is between 55°F and 65°F, the supply set point changes according to the outdoor air reset function. A visual representation of this is shown below.



Local: The supply set point will be a constant temperature set from the controller (adj.).

BUILDING FREEZE PROTECTION: If the supply air temperature drops below 35°F (adj.) for 300s (adj.), the controller will de-energize the unit and activate the alarm output.

TEMPERATURE PROTECTION: The controller will enable the supply fan to modulate down to help the unit keep up with heating demand in the event of wheel failure or the unit operating outside design conditions. (This can be enabled under the manufacturer menu in the controller)

FROST CONTROL: Frost control for the energy wheel is enabled when frost is present on the wheel; based on the outside air temperature and the pressure drop across the wheel. If the outdoor air temperature is below 5°F – 2°F hysteresis, adj. and the differential pressure across the wheel is about 1.5", adj. frost control will enable.

Timed Exhaust: When frosting is occurring, the supply blower is cycled (30 min. ON / 5 min. OFF, adj.) to allow the warm exhaust air to defrost the wheel. Once either the pressure drop decreases below the pressure switch set point, or the outdoor air temperature increases above the temperature set point, the unit will resume normal operation.

ALARMS INDICATION: The controller will display alarms and have one digital output for remote indication of an alarm condition. Possible alarms include:

Dirty Wheel Alarm: The controller monitors pressure across the wheel and sends an alarm in the case of an increased pressure drop.

Supply and Exhaust Air Alarm: The controller monitors the proving switch on each blower and sends an alarm in the case of either blower proving switch not engaging for 30s (adj.).

Temperature Sensor Alarm: The controller sends an alarm in the case of a failed air temperature sensor.

Accessories: The following accessories will be included with the unit to expand the functionality or usability of the controller.

GREENHECK
Building Value in Air.

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Unit Warranty

Limited Warranty

Greenheck warrants this equipment to be free from defects in material and workmanship for a period of 1 year(s) from the purchase date. The energy recovery wheel is warranted to be free from defects in material and workmanship for a period of five years from the purchase date. Any component which proves defective during the warranty period will be repaired, or replaced, at Greenheck's sole option when returned to our factory, transportation prepaid.

The warranty does not include labor costs associated with troubleshooting, removal, or installation. Greenheck will not be liable for any consequential, punitive, or incidental damages resulting from use, repair, or operation of any Greenheck product.

This warranty is exclusive, and is in lieu of all other warranties, whether written, oral or implied, including the warranty of merchantability and the warranty of fitness for a particular purpose.

Appendix N - LEED Scorecard

LEED 2009 for New Construction and Major Renovations

Project Checklist

Project Name

Date

Sustainable Sites — Possible Points: 26

Y	?	N				Points
16		10				
Y			Prereq 1		Construction Activity Pollution Prevention	
		1	Credit 1		Site Selection	1
		5	Credit 2		Development Density and Community Connectivity	5
		1	Credit 3		Brownfield Redevelopment	1
6			Credit 4.1		Alternative Transportation—Public Transportation Access	6
1			Credit 4.2		Alternative Transportation—Bicycle Storage and Changing Rooms	1
3			Credit 4.3		Alternative Transportation—Low-Emitting and Fuel-Efficient Vehicles	3
2			Credit 4.4		Alternative Transportation—Parking Capacity	2
1			Credit 5.1		Site Development—Protect or Restore Habitat	1
1			Credit 5.2		Site Development—Maximize Open Space	1
1			Credit 6.1		Stormwater Design—Quantity Control	1
1			Credit 6.2		Stormwater Design—Quality Control	1
		1	Credit 7.1		Heat Island Effect—Non-roof	1
		1	Credit 7.2		Heat Island Effect—Roof	1
		1	Credit 8		Light Pollution Reduction	1

Water Efficiency — Possible Points: 10

Y	?	N			Points
8					
Y			Prereq 1	Water Use Reduction—20% Reduction	
4			Credit 1	Water Efficient Landscaping	2 to 4
2			Credit 2	Innovative Wastewater Technologies	2
2			Credit 3	Water Use Reduction	2 to 4

Energy and Atmosphere — Possible Points: 35

Y	?	N			Points
21					
Y			Prereq 1	Fundamental Commissioning of Building Energy Systems	
Y			Prereq 2	Minimum Energy Performance	
Y			Prereq 3	Fundamental Refrigerant Management	
10			Credit 1	Optimize Energy Performance	1 to 19
2			Credit 2	On-Site Renewable Energy	1 to 7
2			Credit 3	Enhanced Commissioning	2
2			Credit 4	Enhanced Refrigerant Management	2
3			Credit 5	Measurement and Verification	3
2			Credit 6	Green Power	2

Materials and Resources — Possible Points: 14

Y	?	N			Points
4		9			
Y			Prereq 1	Storage and Collection of Recyclables	
		3	Credit 1.1	Building Reuse—Maintain Existing Walls, Floors, and Roof	1 to 3
		1	Credit 1.2	Building Reuse—Maintain 50% of Interior Non-Structural Elements	1
		2	Credit 2	Construction Waste Management	1 to 2
		2	Credit 3	Materials Reuse	1 to 2

Materials and Resources, Continued

Y	?	N			Points
1			Credit 4	Recycled Content	1 to 2
2			Credit 5	Regional Materials	1 to 2
		1	Credit 6	Rapidly Renewable Materials	1
1			Credit 7	Certified Wood	1

Indoor Environmental Quality — Possible Points: 15

Y	?	N			Points
12		3			
Y			Prereq 1	Minimum Indoor Air Quality Performance	
Y			Prereq 2	Environmental Tobacco Smoke (ETS) Control	
1			Credit 1	Outdoor Air Delivery Monitoring	1
		1	Credit 2	Increased Ventilation	1
1			Credit 3.1	Construction IAQ Management Plan—During Construction	1
1			Credit 3.2	Construction IAQ Management Plan—Before Occupancy	1
1			Credit 4.1	Low-Emitting Materials—Adhesives and Sealants	1
1			Credit 4.2	Low-Emitting Materials—Paints and Coatings	1
1			Credit 4.3	Low-Emitting Materials—Flooring Systems	1
1			Credit 4.4	Low-Emitting Materials—Composite Wood and Agrifiber Products	1
1			Credit 5	Indoor Chemical and Pollutant Source Control	1
1			Credit 6.1	Controllability of Systems—Lighting	1
1			Credit 6.2	Controllability of Systems—Thermal Comfort	1
1			Credit 7.1	Thermal Comfort—Design	1
1			Credit 7.2	Thermal Comfort—Verification	1
		1	Credit 8.1	Daylight and Views—Daylight	1
		1	Credit 8.2	Daylight and Views—Views	1

Innovation and Design Process — Possible Points: 6

Y	?	N			Points
3		3			
1			Credit 1.1	Innovation in Design: Specific Title	1
1			Credit 1.2	Innovation in Design: Specific Title	1
		1	Credit 1.3	Innovation in Design: Specific Title	1
		1	Credit 1.4	Innovation in Design: Specific Title	1
		1	Credit 1.5	Innovation in Design: Specific Title	1
1			Credit 2	LEED Accredited Professional	1

Regional Priority Credits — Possible Points: 4

Y	?	N			Points
2		2			
1			Credit 1.1	Regional Priority: Specific Credit	1
1			Credit 1.2	Regional Priority: Specific Credit	1
		1	Credit 1.3	Regional Priority: Specific Credit	1
		1	Credit 1.4	Regional Priority: Specific Credit	1

Total — Possible Points: 110

Y	?	N
66		27

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

Appendix O - Energy Analysis Report

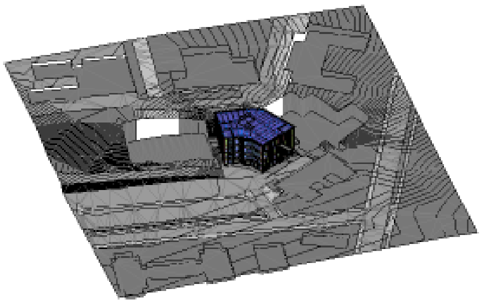
AUTODESK.

AREN Building

Main Model - Final Analysis

Analyzed at 3/20/2017 9:35:54 PM

Energy Analysis Result



Building Performance Factors

Location:	Worcester, MA
Weather Station:	52500
Outdoor Temperature:	Max: 93°F/Min: -9°F
Floor Area:	33,239 sf
Exterior Wall Area:	15,727 sf
Average Lighting Power:	0.99 W / ft²
People:	583 people
Exterior Window Ratio:	0.32
Electrical Cost:	$0.14 / kWh
Fuel Cost:	$1.16 / Therm

Energy Use Intensity

Electricity EUI:	9 kWh / sf / yr
Fuel EUI:	68 kBtu / sf / yr
Total EUI:	98 kBtu / sf / yr

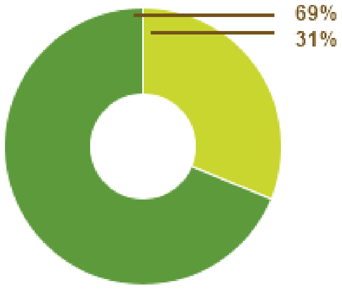
Life Cycle Energy Use/Cost

Life Cycle Electricity Use:	8,963,112 kWh
Life Cycle Fuel Use:	674,221 Therms
Life Cycle Energy Cost:	$938,928

*30-year life and 6.1% discount rate for costs

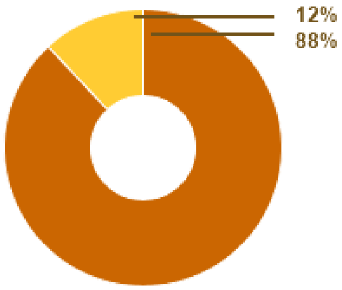
Annual Energy Use/Cost

A125



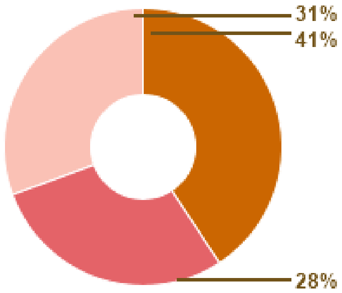
Electricity	31%	$42,933	298,770	kWh
Fuel	69%	$26,004	22,474	Therms
		$68,937		

Energy Use: Fuel



			(Therms)
HVAC	88%	$22,886	19,780
Domestic Hot Water	12%	$3,117	2,693
		$26,003	22,473

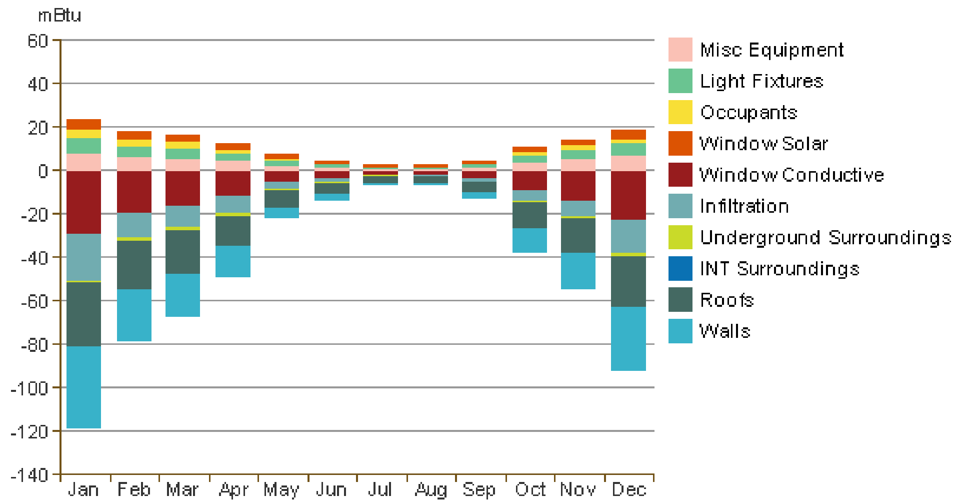
Energy Use: Electricity



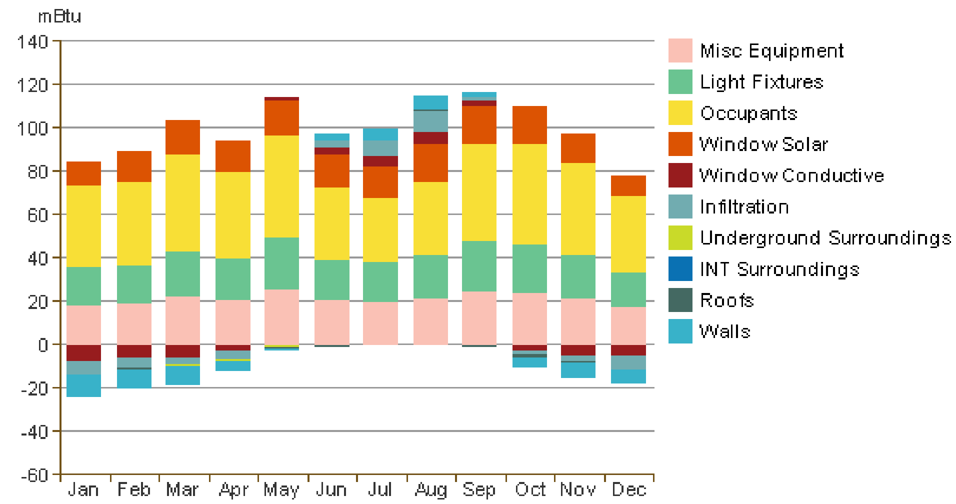
			(kWh)
HVAC	41%	$17,365	120,848
Lighting	28%	$12,208	84,956
Misc Equipment	31%	$13,039	90,739
		$42,612	296,543

Monthly Heating Load

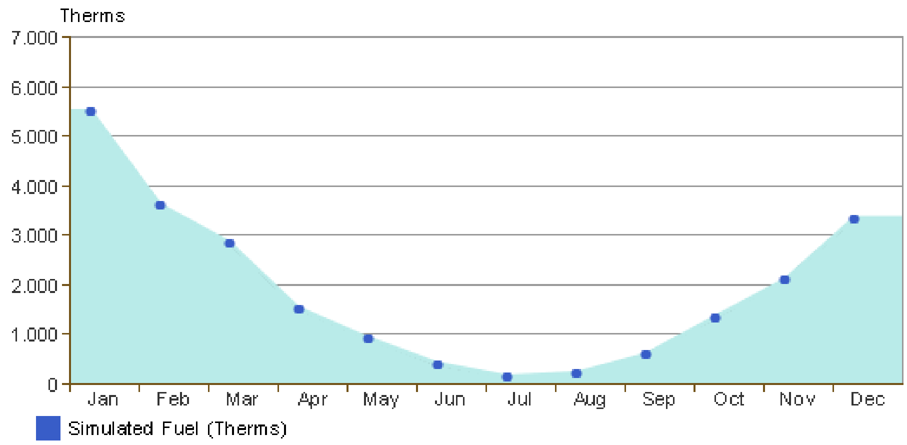
A126



Monthly Cooling Load

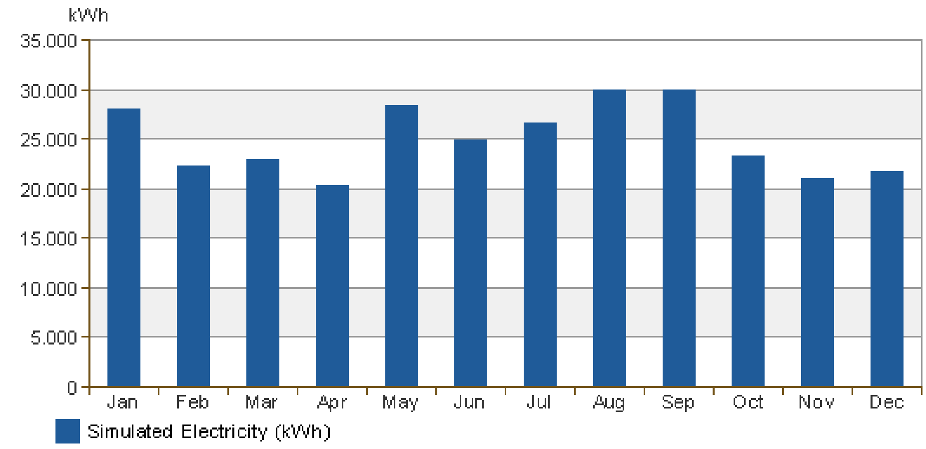


Monthly Fuel Consumption

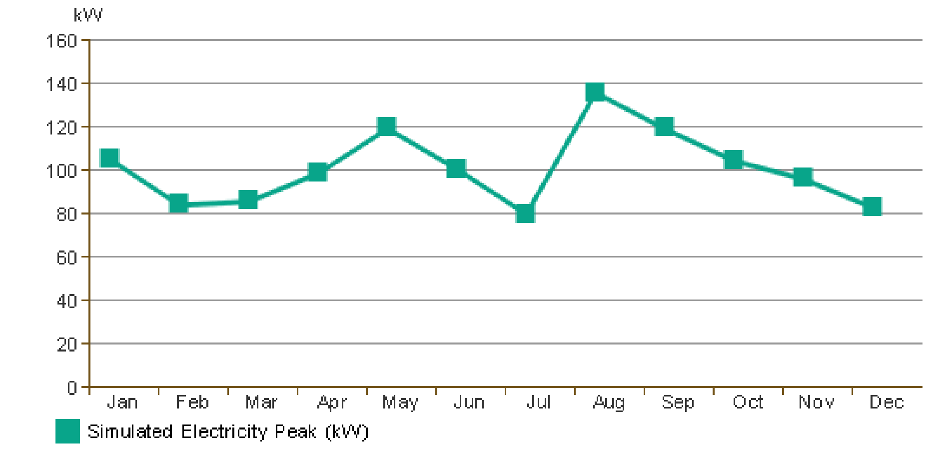


Monthly Electricity Consumption

A127



Monthly Peak Demand



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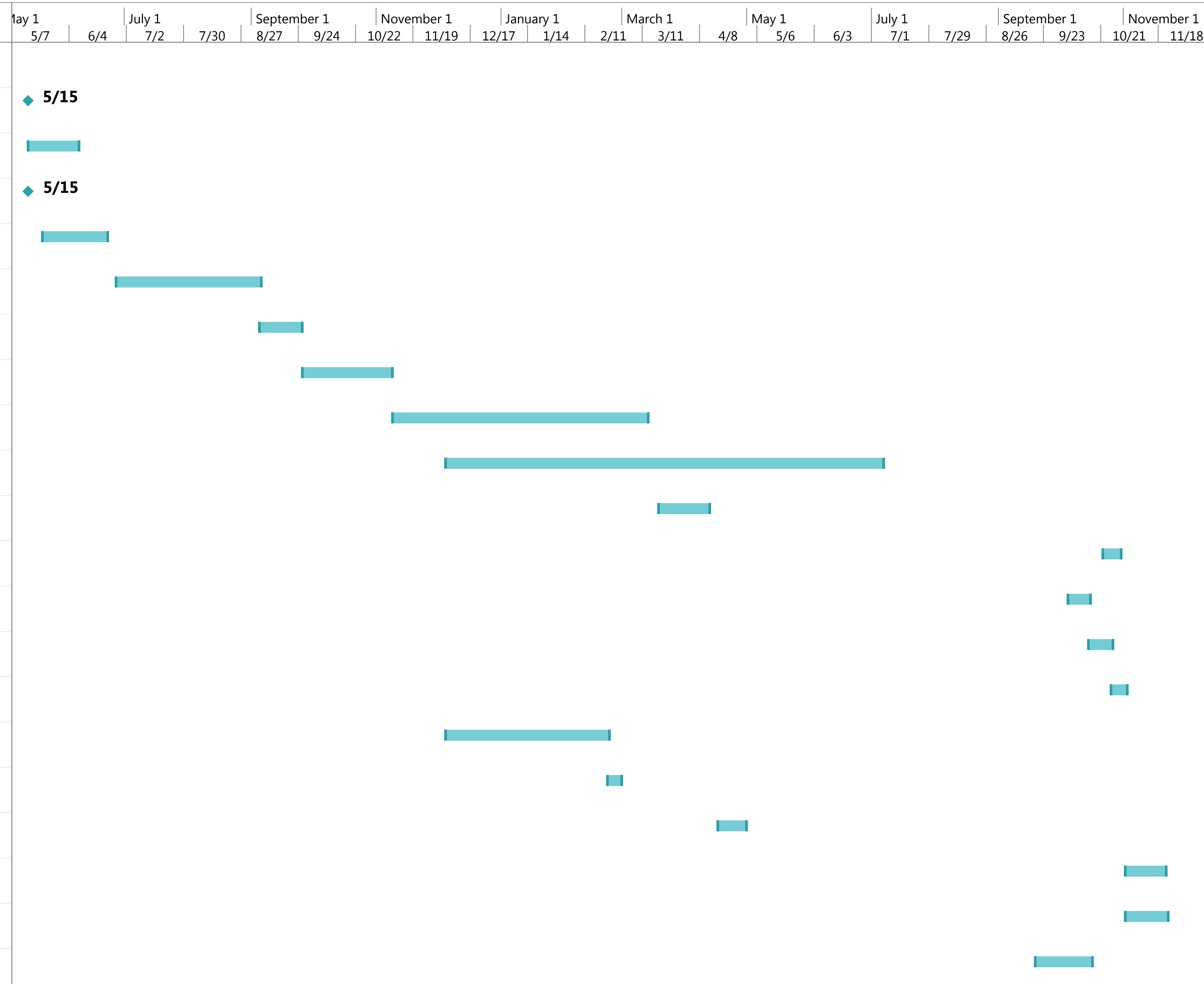
Energy Analysis Data

Appendix P - Schedule

A128

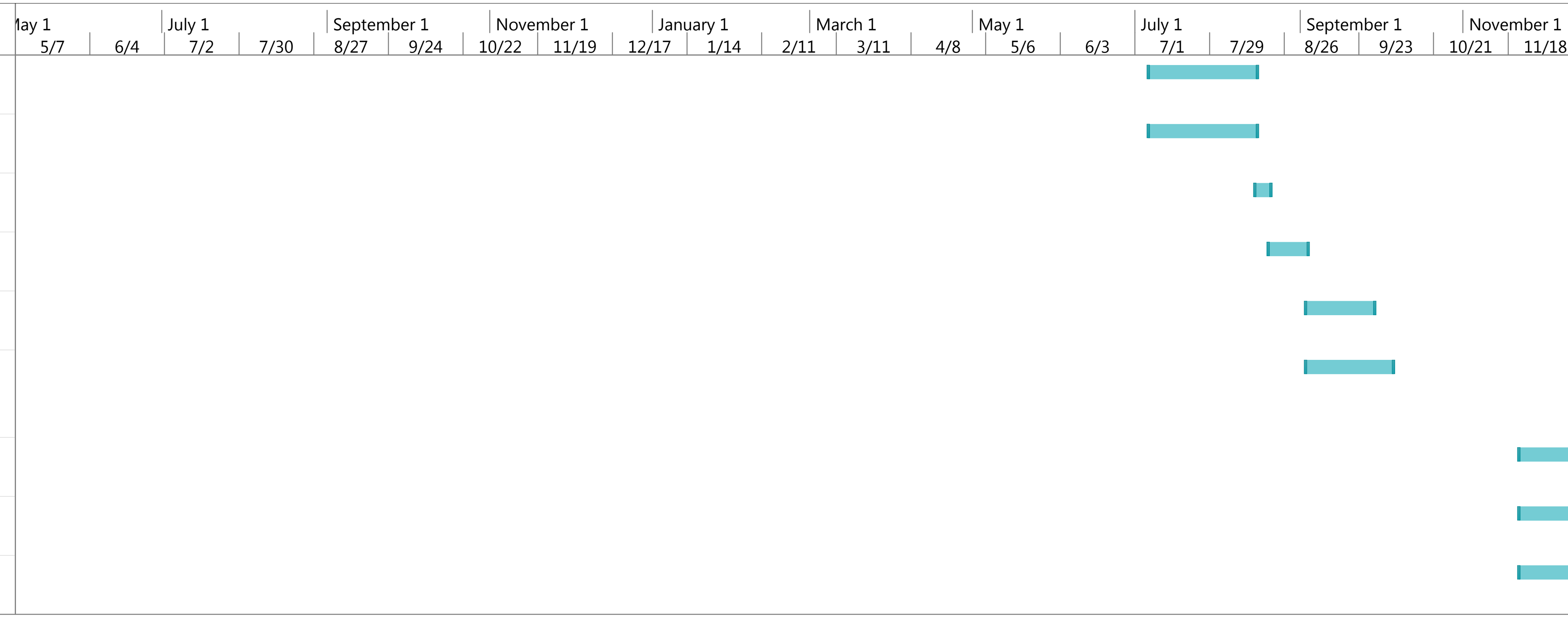
ID		Task Mode	Task Name	Duration	Start	Finish
1						
2			Project Begins	0 days	Mon 5/15/17	Mon 5/15/17
3			Construction Documents	19 days	Mon 5/15/17	Thu 6/8/17
4			Construction Finances	0 days	Mon 5/15/17	Mon 5/15/17
5			Building Design	24 days	Mon 5/22/17	Thu 6/22/17
6			Excavation and Footings	51 days	Tue 6/27/17	Tue 9/5/17
7			Foundation	15 days	Tue 9/5/17	Mon 9/25/17
8			Steel Erection	32 days	Tue 9/26/17	Wed 11/8/17
9			Floor Construction	89 days	Thu 11/9/17	Tue 3/13/18
10			Roof Construction	154 days	Tue 12/5/17	Fri 7/6/18
11			Exterior Walls	19 days	Mon 3/19/18	Thu 4/12/18
12			Exterior Windows	7 days	Mon 10/22/18	Tue 10/30/18
13			Exterior Doors	7 days	Fri 10/5/18	Mon 10/15/18
14			Partitions	10 days	Mon 10/15/18	Fri 10/26/18
15			Interior Doors	6 days	Fri 10/26/18	Fri 11/2/18
16			Stair Construction	58 days	Tue 12/5/17	Thu 2/22/18
17			Stair Finishes	5 days	Thu 2/22/18	Wed 2/28/18
18			Wall Finishes	10 days	Tue 4/17/18	Mon 4/30/18
19			Floor Finishes	14 days	Fri 11/2/18	Wed 11/21/18
20			Ceiling Finishes	15 days	Fri 11/2/18	Thu 11/22/18
21			Elevators	20 days	Wed 9/19/18	Tue 10/16/18



Project: FinalMQPSchuedule.mp
Date: Mon 3/20/17

Task		Project Summary		Manual Task		Start-only		Deadline	
Split		Inactive Task		Duration-only		Finish-only		Progress	
Milestone	◆	Inactive Milestone		Manual Summary Rollup		External Tasks		Manual Progress	
Summary		Inactive Summary		Manual Summary		External Milestone			

ID		Task Mode	Task Name	Duration	Start	Finish
22			Plumbing Fixtures	29 days	Fri 7/6/18	Wed 8/15/18
23			HVAC Fixtures	29 days	Fri 7/6/18	Wed 8/15/18
24			Fire Protection Sprinkler Systems	4 days	Wed 8/15/18	Mon 8/20/18
25			Electrical Systems	11 days	Mon 8/20/18	Mon 9/3/18
26			Lighting and Branch Wiring	20 days	Mon 9/3/18	Fri 9/28/18
27			Communications and Security Systems	25 days	Mon 9/3/18	Fri 10/5/18
28			Commerical Equipment	15 days	Thu 11/22/18	Wed 12/12/18
29			Fixed Furnishings	15 days	Thu 11/22/18	Wed 12/12/18
30			Moveable Furnishings	15 days	Thu 11/22/18	Wed 12/12/18



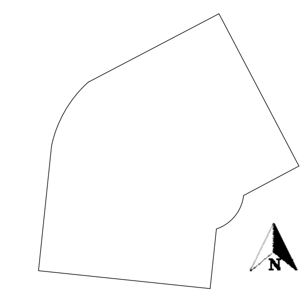
Project: FinalMQPSchuedule.mp
Date: Mon 3/20/17

Task		Project Summary		Manual Task		Start-only		Deadline	
Split		Inactive Task		Duration-only		Finish-only		Progress	
Milestone		Inactive Milestone		Manual Summary Rollup		External Tasks		Manual Progress	
Summary		Inactive Summary		Manual Summary		External Milestone			

Design of an Architectural Engineering Building for Worcester Polytechnic Institute's Campus

Worcester Polytechnic Institute
100 Institute Rd.
Worcester, MA 01609

Design of AREN Building for WPI Campus



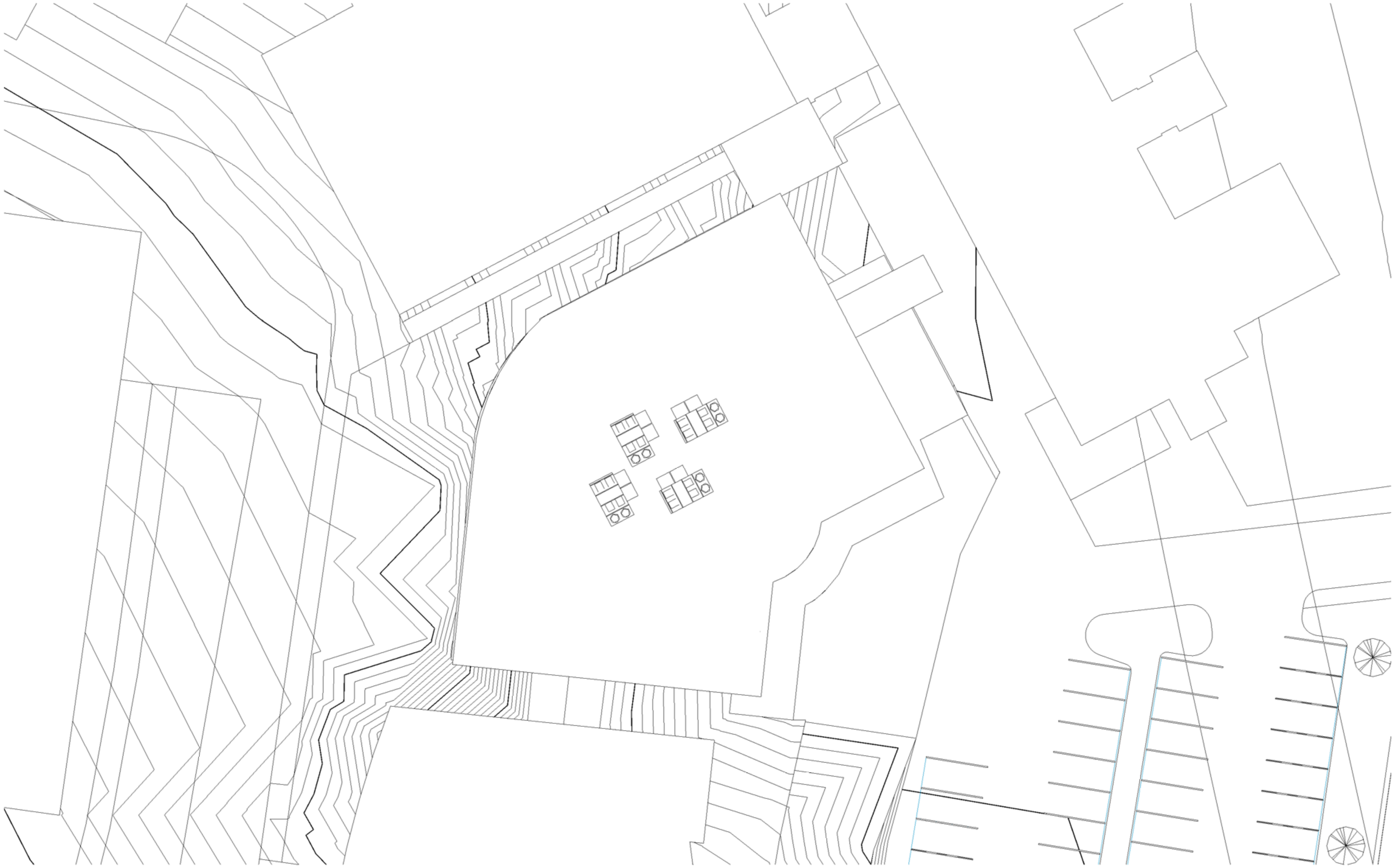
Design Documents

No.	Description	Date

Cover Sheet

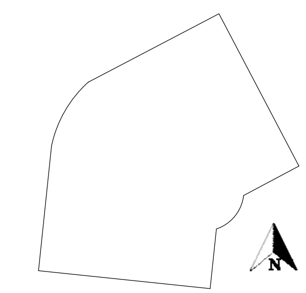
Scale	
Date	03/03/2016
Drawn by	KM
Checked by	MT/CT/MH

A000



Worcester Polytechnic Institute
100 Institute Rd.
Worcester, MA 01609

Design of AREN Building for WPI Campus



Design Documents

No.	Description	Date

Site Plan

Scale	1/32" = 1'-0"
Date	03/03/2016
Drawn by	KEM
Checked by	MCH, CLT, MCT

A100

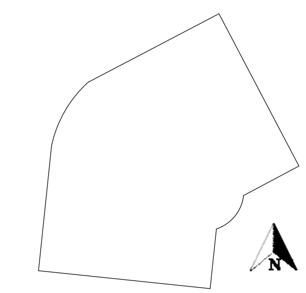
Room Schedule - First Floor	
Number	Type
2	Lobby
1	TA Office
6	Mechanical Room
5	Bathroom
4	Bathroom
3	Storage Room
7	South Egress Stairs

1 Level 1
1/16" = 1'-0"

WPI

Worcester Polytechnic Institute
100 Institute Rd.
Worcester, MA 01609

Design of AREN Building for WPI Campus



Design Documents

No.	Description	Date

First Floor Plan

Scale	1/16" = 1'-0"
Date	03/03/2016
Drawn by	KEM
Checked by	MCH, CLT, MCT

A101

Room Schedule - Second Floor	
Number	Type
8	North Egress Stairs
9	Office
10	Office
11	Office
12	Office
13	Office
14	Office
15	Office
16	Office
17	Office
18	Office
19	Office
20	Storage Room
21	Office
22	Office
23	Open Area
24	Conference Room
25	Admin Area
26	Storage Room
27	Bathroom
28	Bathroom
29	Conference Room
30	Copy Room
31	Faculty Lounge
32	Computer Lab
33	Conference Room

1 Level 2
1/16" = 1'-0"

WPI
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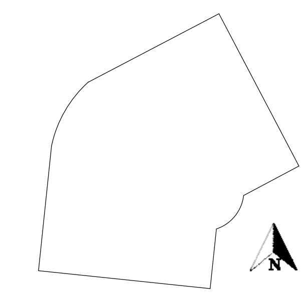
100 Institute Rd.
Worcester, MA 01609

Design of AREN Building for WPI Campus



Design Documents

No.	Description	Date

Second Floor Plan

Scale	1/16" = 1'-0"
Date	03/03/2016
Drawn by	KEM
Checked by	MCH, CLT, MCT

A102

Room Schedule - Third Floor	
Number	Type
34	Studio
35	Studio
36	Presentation Room
37	Presentation Room
38	Open Area
39	Classroom
40	Tech Suite
41	Tech Suite
42	Study Stairs
43	Studio
44	Bathroom
45	Bathroom
46	Mechanical Shaft

1 Level 3
1/16" = 1'-0"

Worcester Polytechnic Institute
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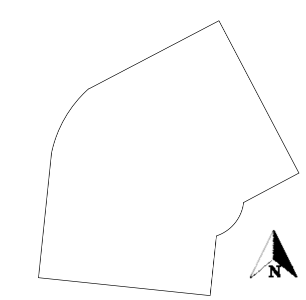
Worcester, MA 01609

Design of AREN Building for WPI Campus



Design Documents

No.	Description	Date

Third Floor Plan

Scale	1/16" = 1'-0"
Date	03/03/2016
Drawn by	KEM
Checked by	MCH, CLT, MCT

A103

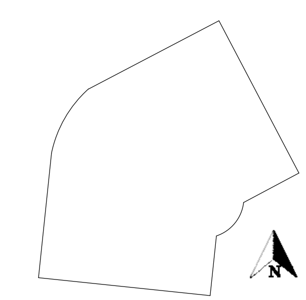
Room Schedule - Fourth Floor	
Number	Type
47	Lecture Hall
48	Classroom
49	Classroom
50	Tech Suite
51	Tech Suite
52	Tech Suite
53	Classroom
54	Open Area
55	Conference Room
56	Lecture Hall
57	Conference Room

1 Level 4
1/16" = 1'-0"

WPI

Worcester Polytechnic Institute
100 Institute Rd.
Worcester, MA 01609

Design of AREN Building for WPI Campus



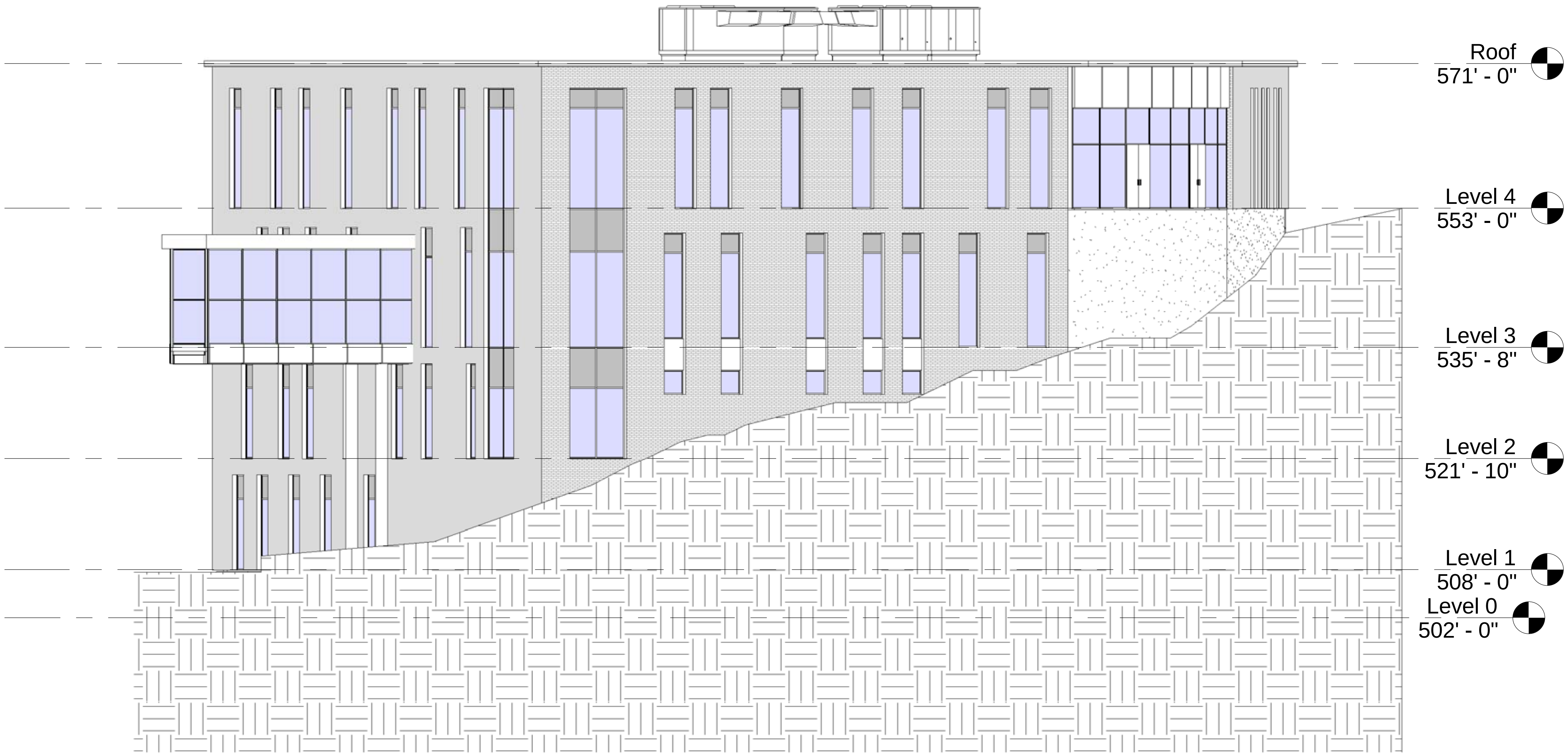
Design Documents

No.	Description	Date

Fourth Floor Plan

Scale	1/16" = 1'-0"
Date	03/03/2016
Drawn by	KEM
Checked by	MCH, CLT, MCT

A104



1 North
1/16" = 1'-0"

Worcester Polytechnic Institute
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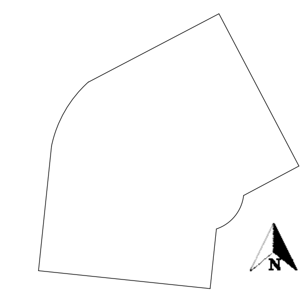
Worcester, MA 01609

Design of AREN Building for WPI Campus



Design Documents

No.	Description	Date

North Elevation

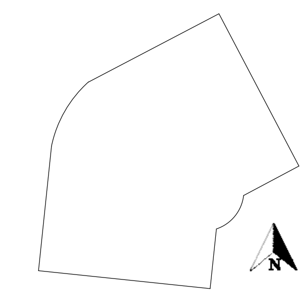
Scale	1/16" = 1'-0"
Date	03/03/2016
Drawn by	KEM
Checked by	MCH, CLT, MCT

A201

1 East
1/16" = 1'-0"

Worcester Polytechnic Institute
100 Institute Rd.
Worcester, MA 01609

Design of AREN Building for WPI Campus



Design Documents

No.	Description	Date

East Elevation

Scale	1/16" = 1'-0"
Date	03/03/2016
Drawn by	KEM
Checked by	MCH, CLT, MCT

A202

1 South
1/16" = 1'-0"

WPI

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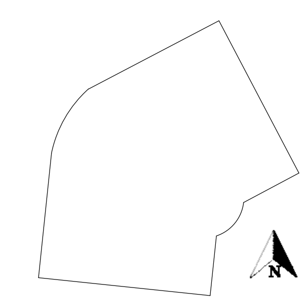
100 Institute Rd.
Worcester, MA 01609

Design of AREN Building for WPI Campus



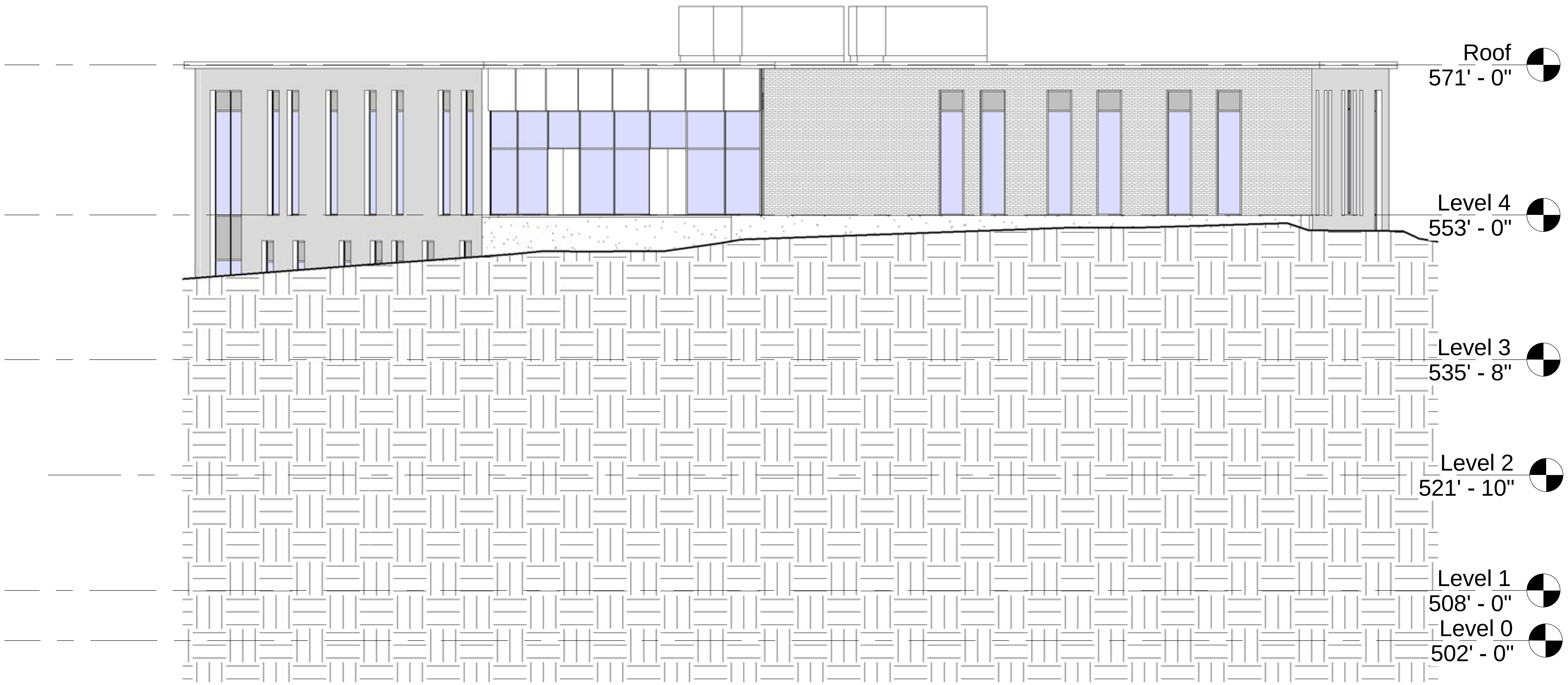
Design Documents

No.	Description	Date

South Elevation

Scale	1/16" = 1'-0"
Date	03/03/2016
Drawn by	KEM
Checked by	MCH, CLT, MCT

A203

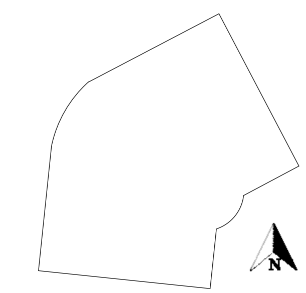


1 West
1/16" = 1'-0"

WPI

Worcester Polytechnic Institute
100 Institute Rd.
Worcester, MA 01609

Design of AREN Building for WPI Campus



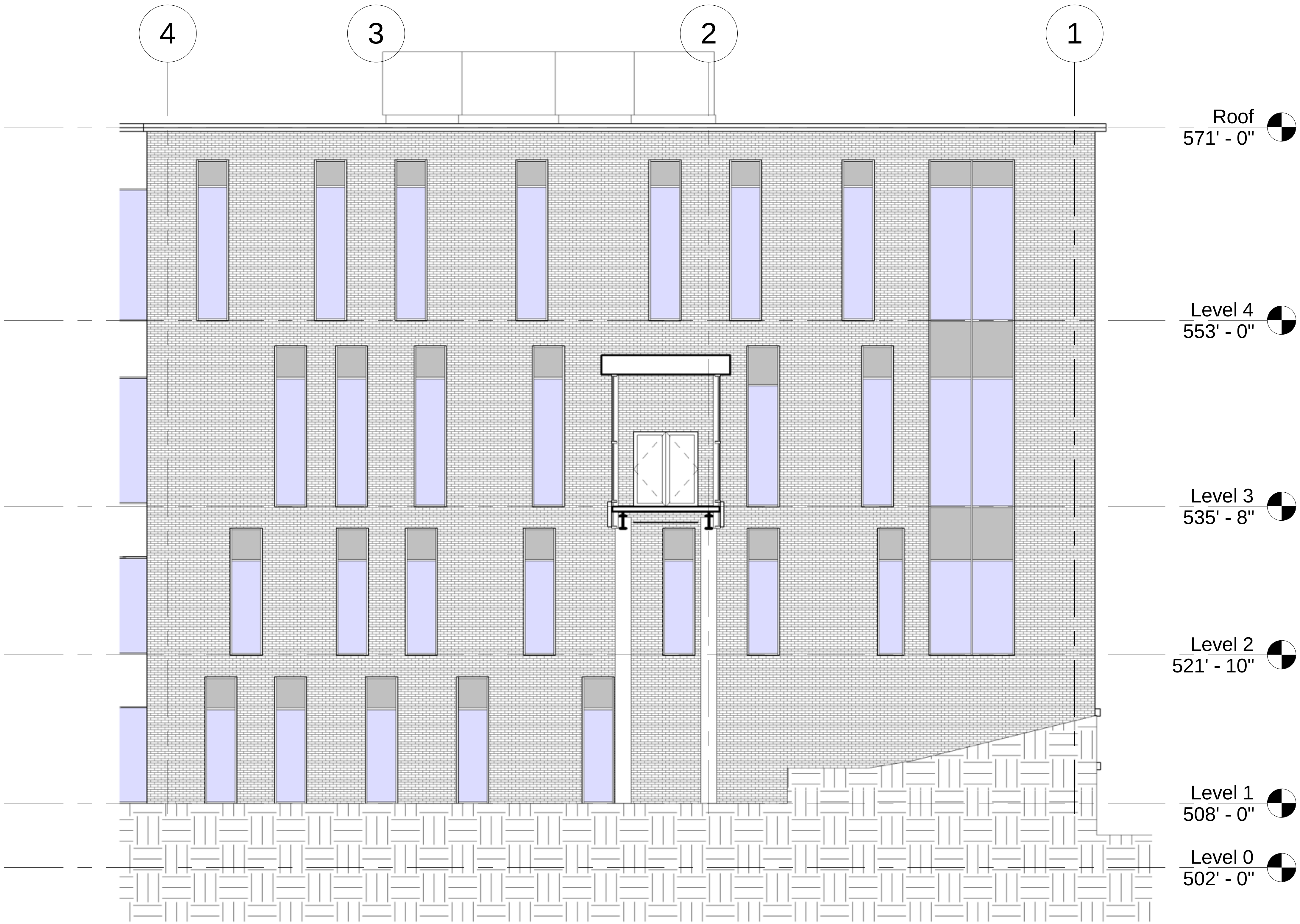
Design Documents

No.	Description	Date

West Elevation

Scale	1/16" = 1'-0"
Date	03/03/2016
Drawn by	KEM
Checked by	MCH, CLT, MCT

A204



1 Northeast Elevation Facing Kaven
3/32" = 1'-0"

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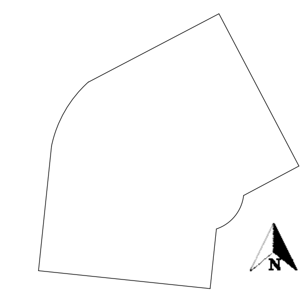
Worcester, MA 01609

Design of AREN Building for WPI Campus



Design Documents

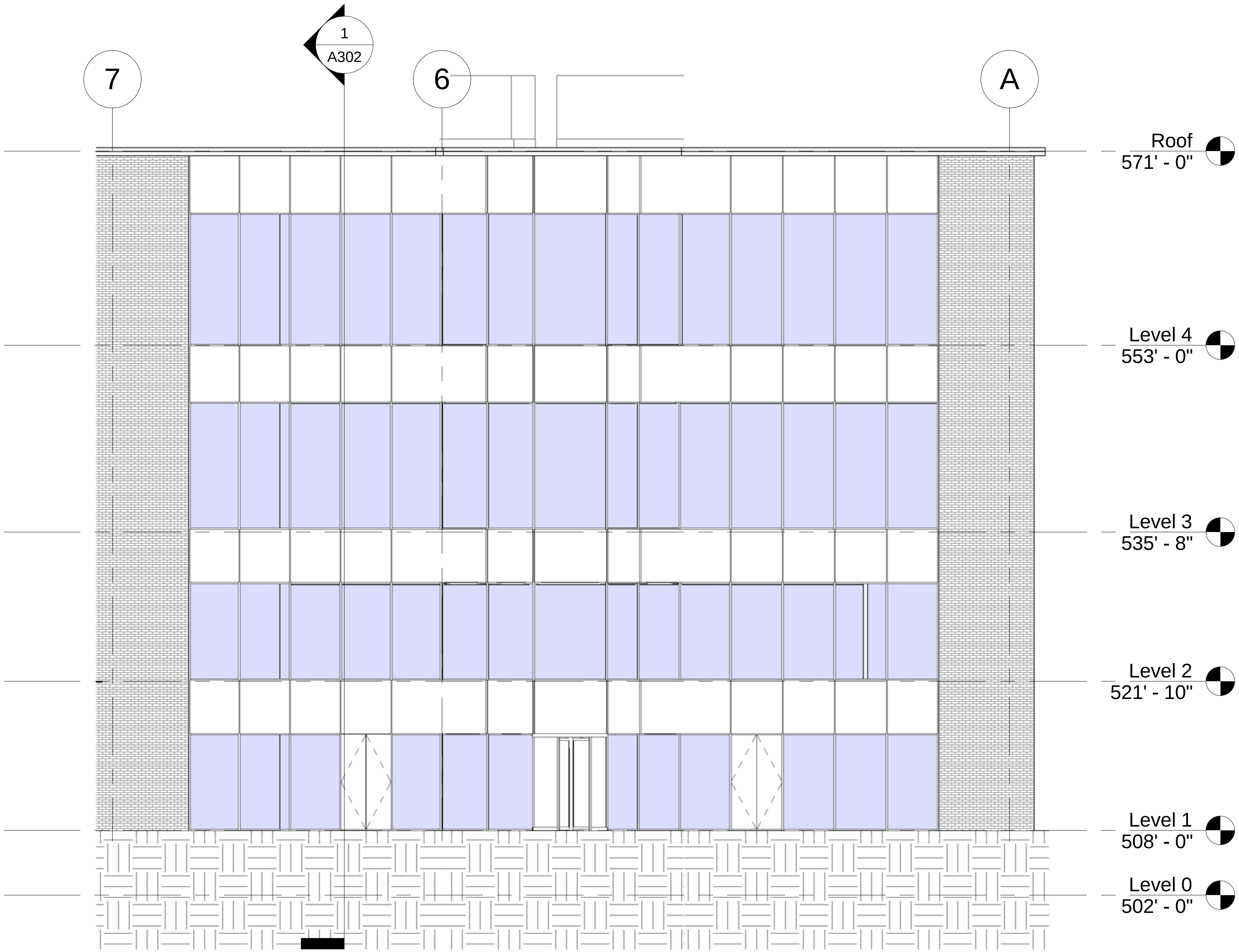
No.	Description	Date

Northeast

Enlarged Elevation

Scale	3/32" = 1'-0"
Date	03/03/2016
Drawn by	KEM
Checked by	MCH, CLT, MCT

A210



2 Southeast Entrance Elevation
3/32" = 1'-0"

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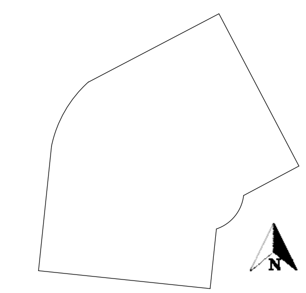
Design of AREN Building for WPI Campus



Design Documents

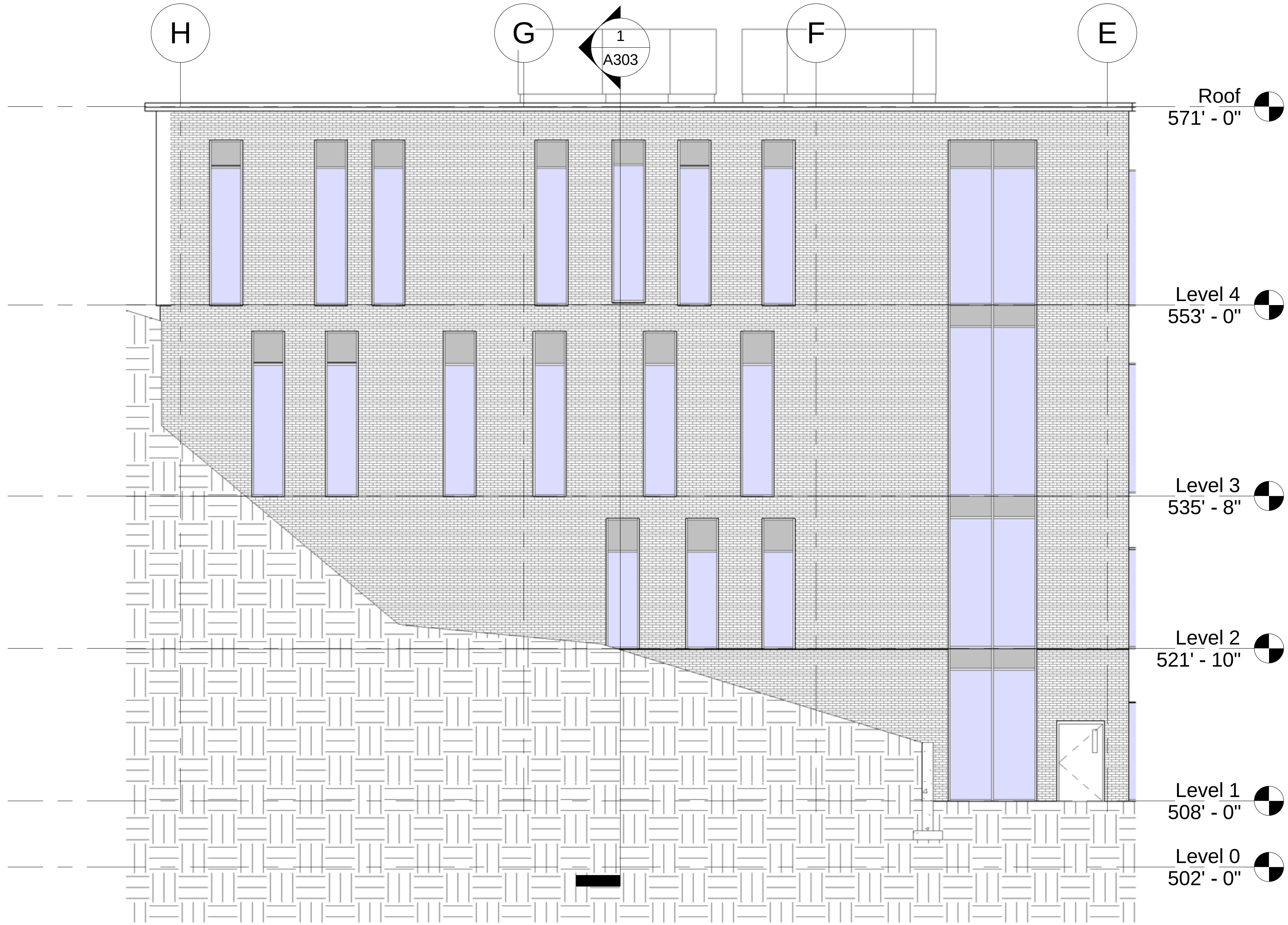
No.	Description	Date

Southeast

Enlarged Elevation

Scale	3/32" = 1'-0"
Date	03/03/2016
Drawn by	KEM
Checked by	MCH, CLT, MCT

A211



1 South Elevation
3/32" = 1'-0"

WPI

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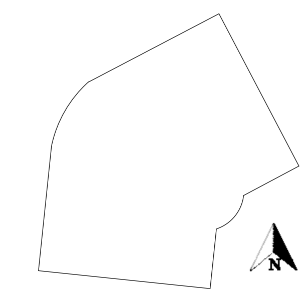
Worcester, MA 01609

Design of AREN Building for WPI Campus



Design Documents

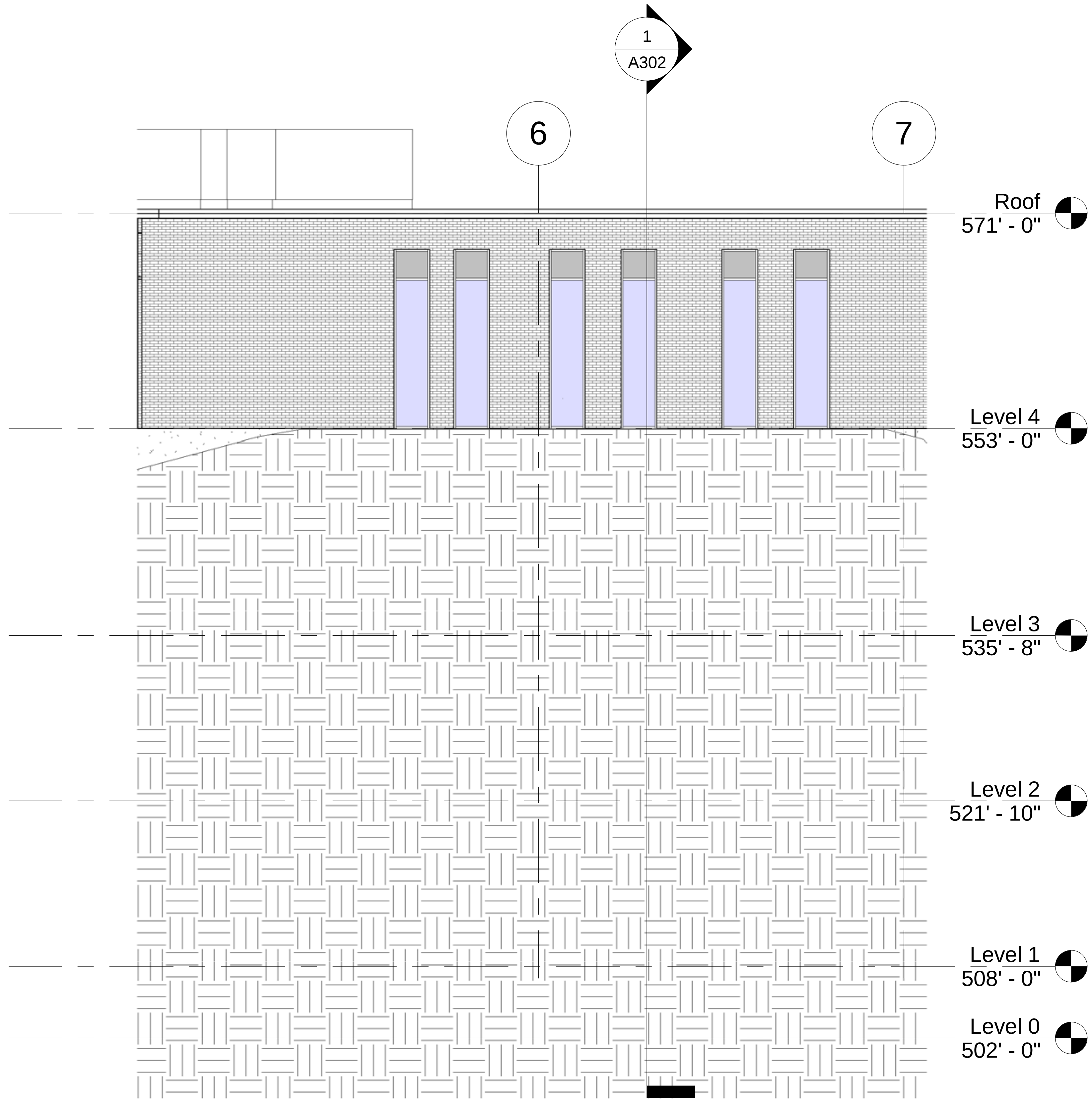
No.	Description	Date

South

Enlarged Elevation

Scale	3/32" = 1'-0"
Date	03/03/2016
Drawn by	KEM
Checked by	MCH, CLT, MCT

A212

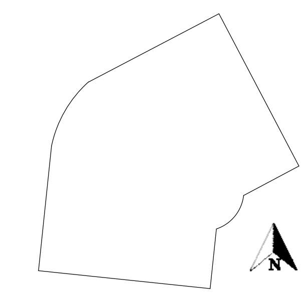


1 West Elevation
3/32" = 1'-0"

WPI

Worcester Polytechnic Institute
100 Institute Rd.
Worcester, MA 01609

Design of AREN Building for WPI Campus



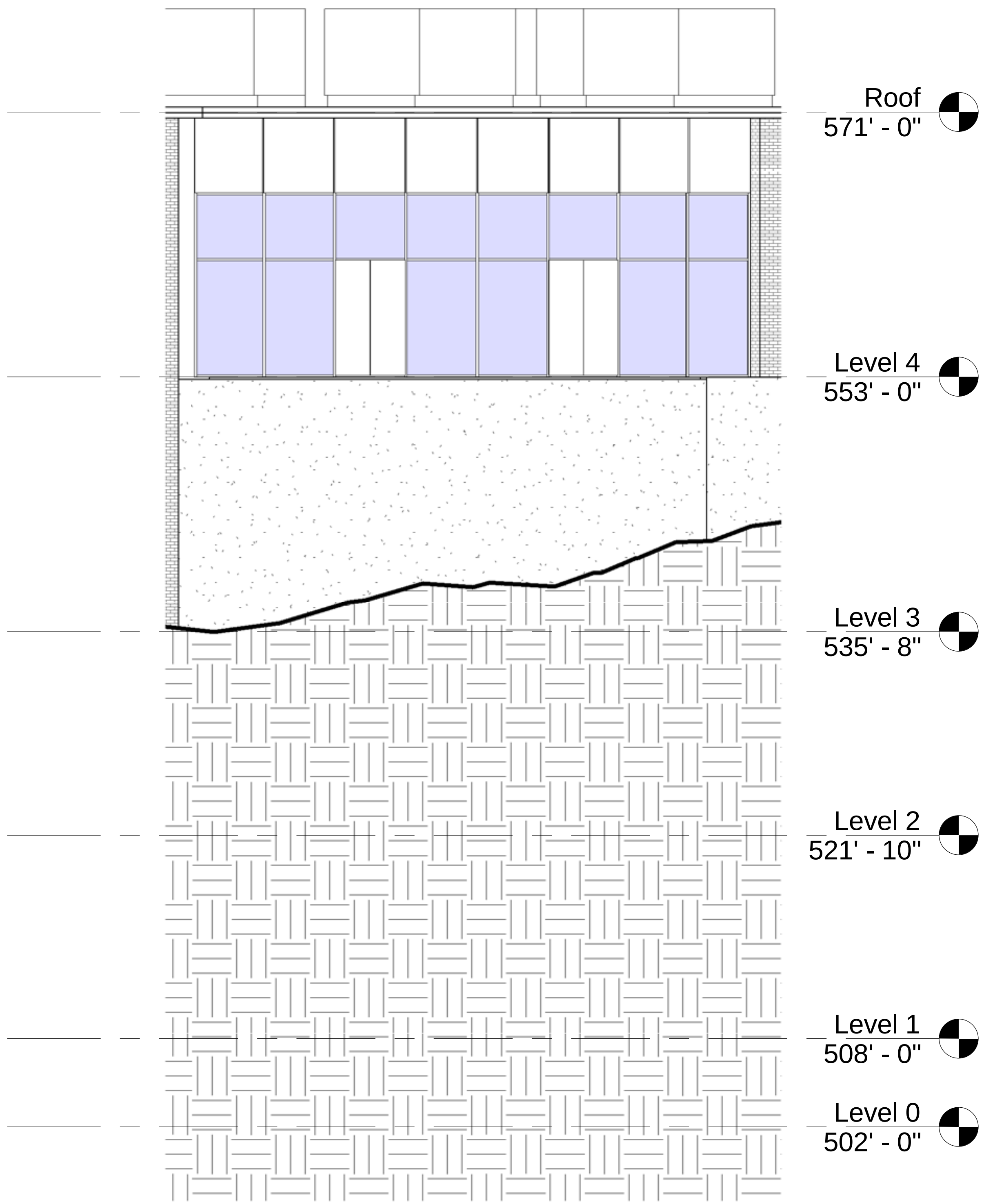
Design Documents

No.	Description	Date

West
Enlarged Elevation

Scale	3/32" = 1'-0"
Date	03/03/2016
Drawn by	KEM
Checked by	MCH, CLT, MCT

A213

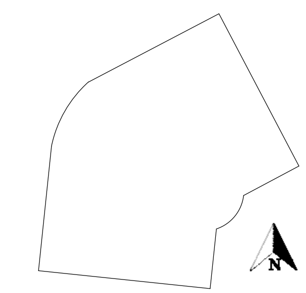


1 Northwest Entrance
3/32" = 1'-0"

WPI

Worcester Polytechnic Institute
100 Institute Rd.
Worcester, MA 01609

Design of AREN Building for WPI Campus



Design Documents

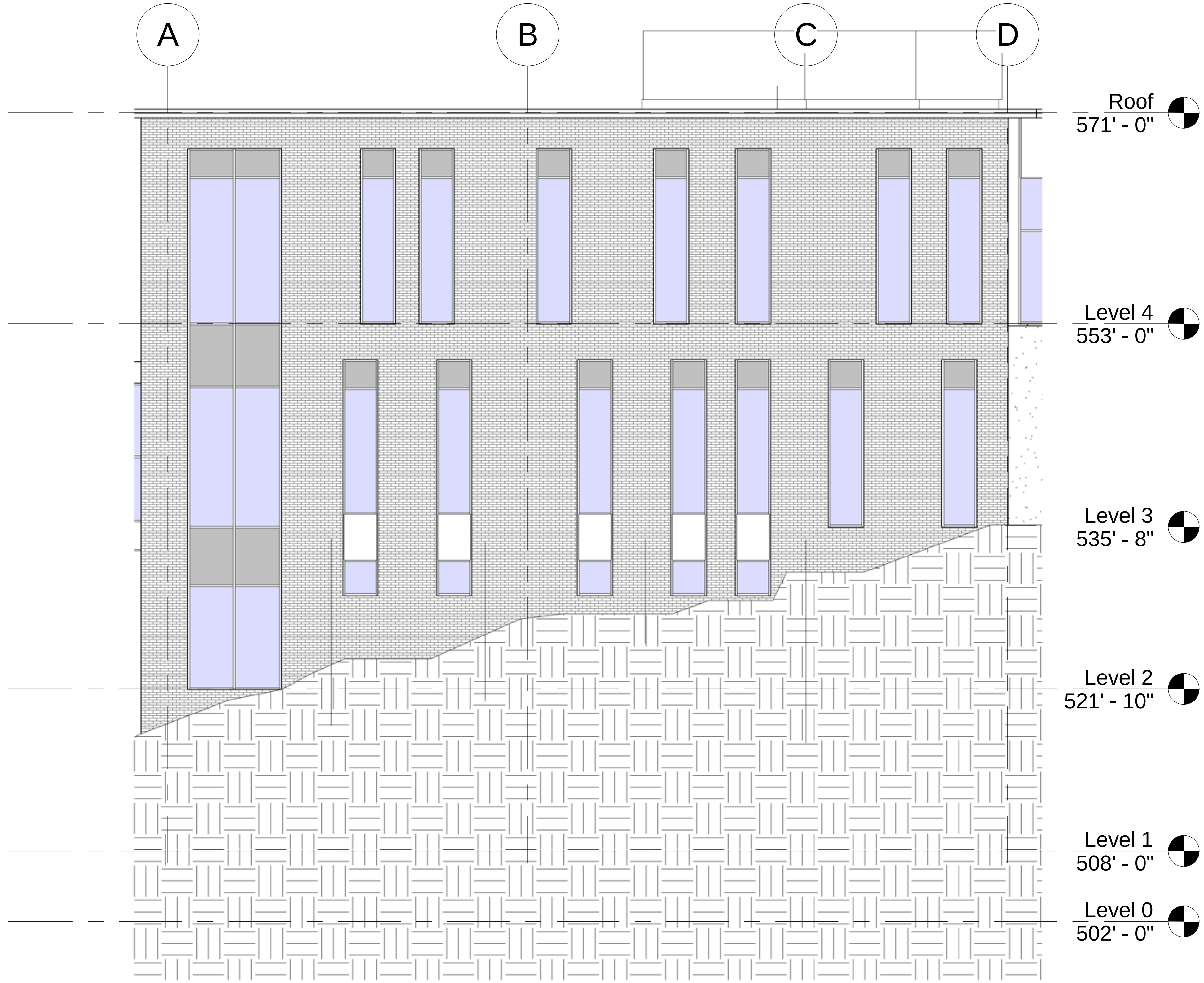
No.	Description	Date

Northwest Entrance

Enlarged Elevation

Scale	3/32" = 1'-0"
Date	03/03/2016
Drawn by	KEM
Checked by	MCH, CLT, MCT

A214

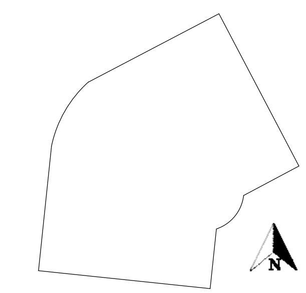


1 Northwest Elevation Facing Campus
3/32" = 1'-0"

WPI

Worcester Polytechnic Institute
100 Institute Rd.
Worcester, MA 01609

Design of AREN Building for WPI Campus



Design Documents

No.	Description	Date

Northwest

Enlarged Elevation

Scale	3/32" = 1'-0"
Date	03/03/2016
Drawn by	KEM
Checked by	MCH, CLT, MCT

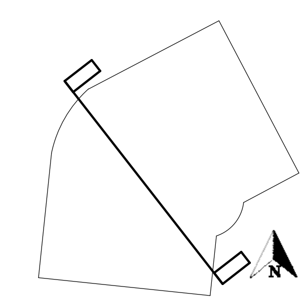
A215

1 Section Through Core Wall
3/32" = 1'-0"

WPI

Worcester Polytechnic Institute
100 Institute Rd.
Worcester, MA 01609

Design of AREN Building for WPI Campus



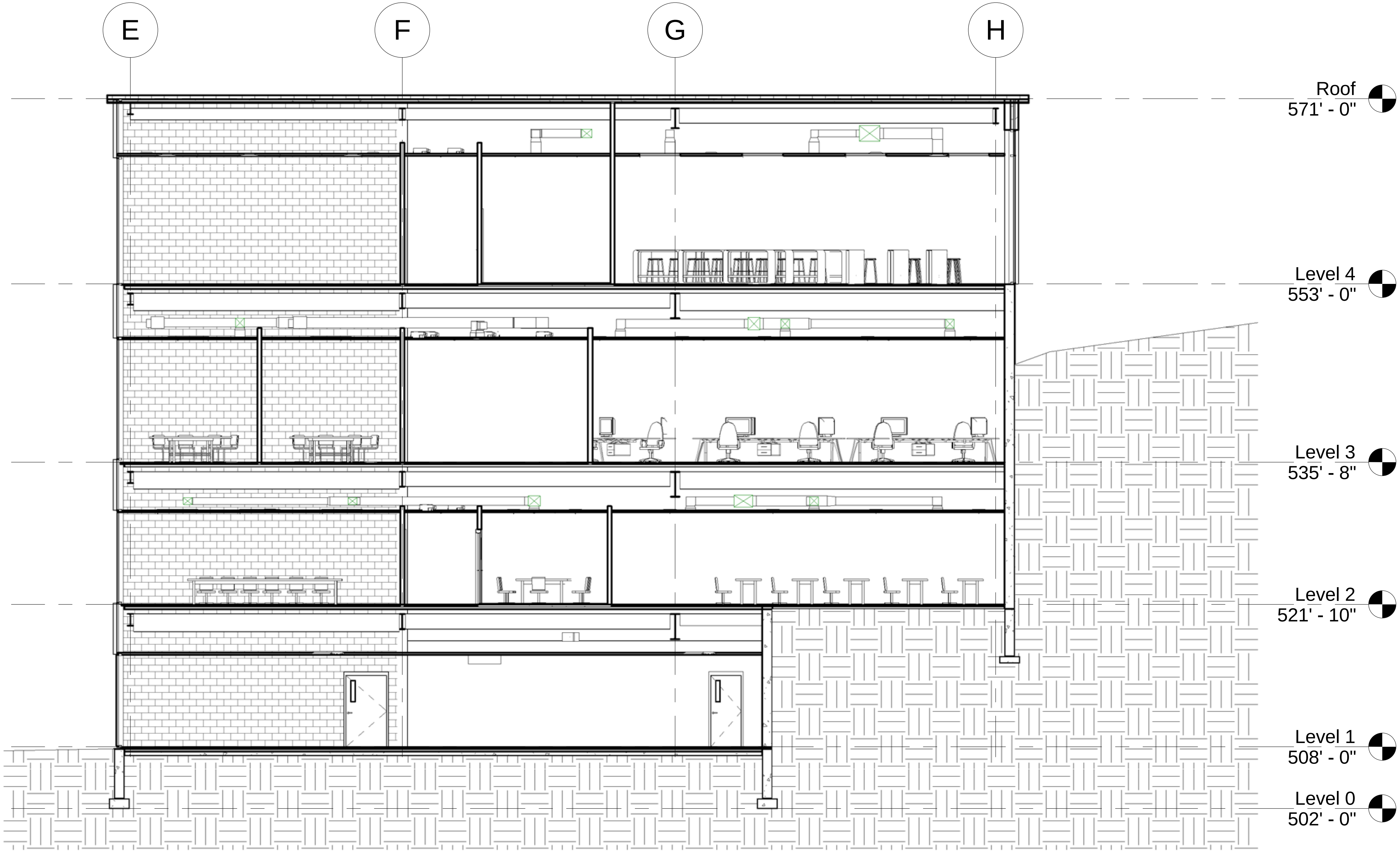
Design Documents

No.	Description	Date

Building Section

Scale	3/32" = 1'-0"
Date	03/03/2016
Drawn by	KEM
Checked by	MCH, CLT, MCT

A301



1 Section between Column Lines 6 & 7
3/32" = 1'-0"

WPI

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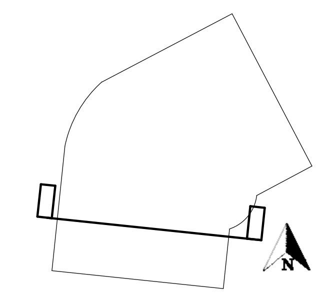
Worcester, MA 01609

Design of AREN Building for WPI Campus



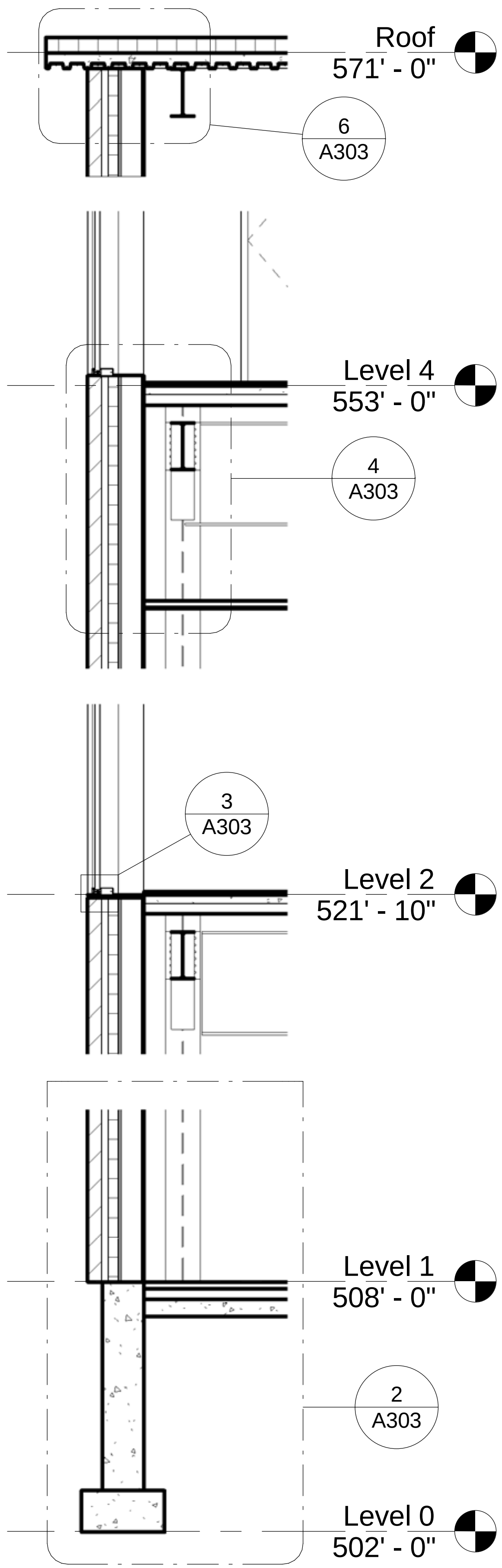
Design Documents

No.	Description	Date

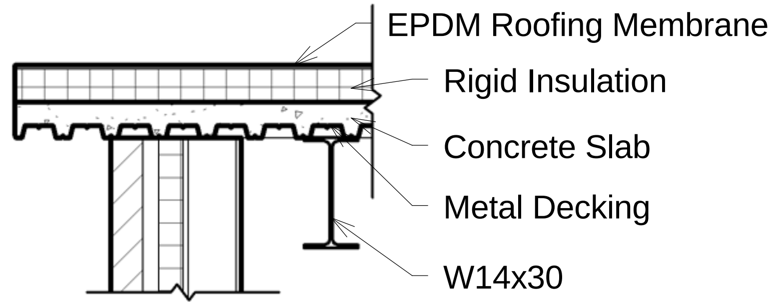
Building Section

Scale	3/32" = 1'-0"
Date	03/03/2016
Drawn by	MT
Checked by	KM/CT/MH

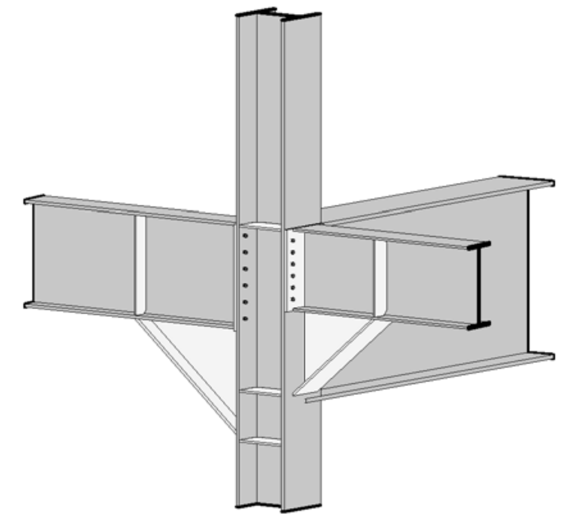
A302



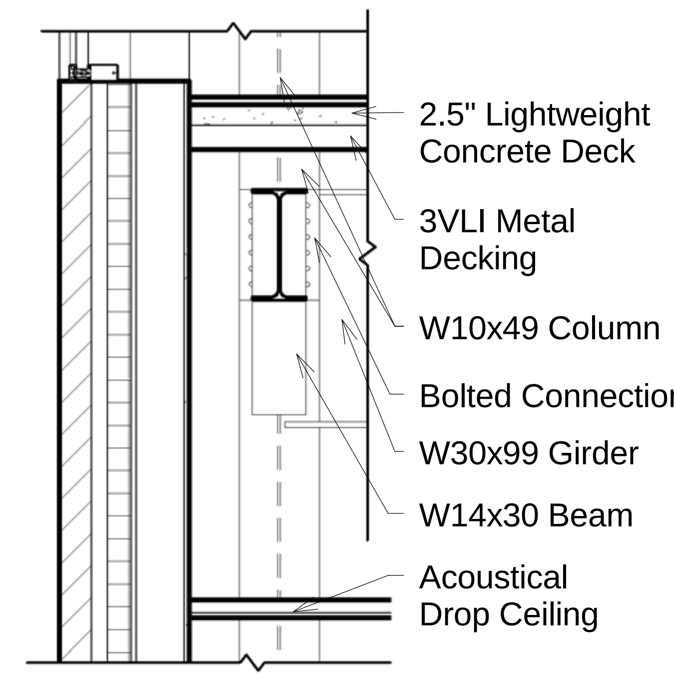
1 Wall Section
1/4" = 1'-0"



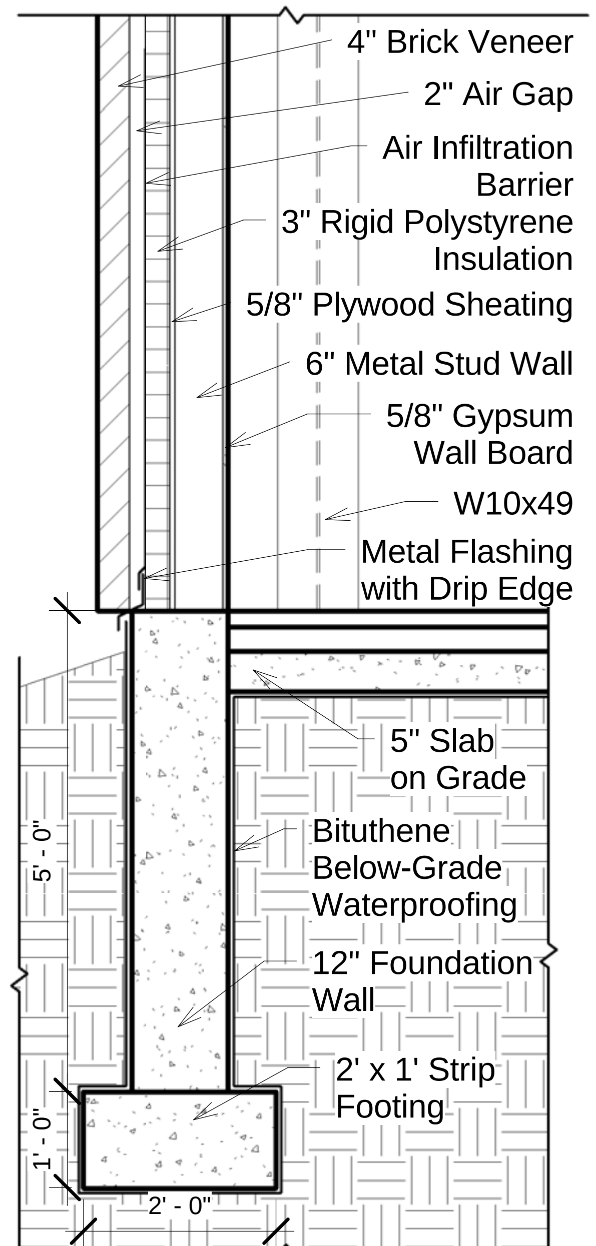
6 Roof Section
1/2" = 1'-0"



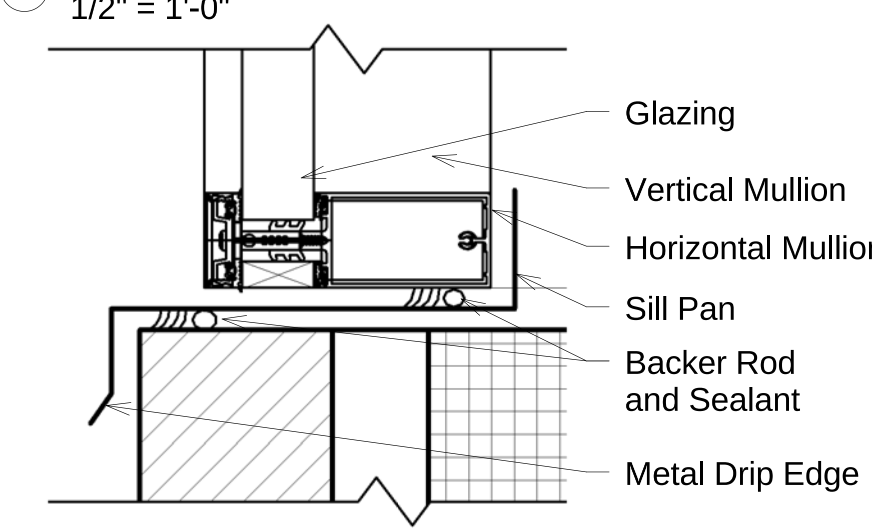
5 Connection Isometric



4 Steel Connection Detail
1/2" = 1'-0"



2 Wall and Foundation Detail
1/2" = 1'-0"

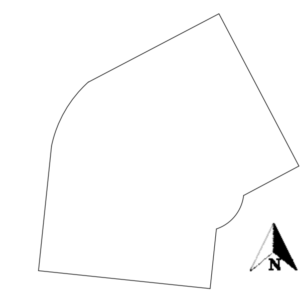


3 Window and Curtain Wall Detail
3" = 1'-0"

WPI

Worcester Polytechnic Institute
100 Institute Rd.
Worcester, MA 01609

Design of AREN Building for WPI Campus



Design Documents

No.	Description	Date

Wall Section

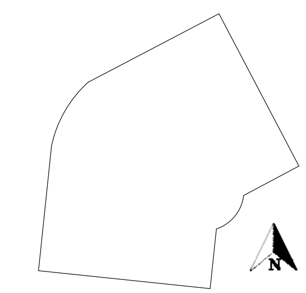
Scale	As indicated
Date	03/03/2016
Drawn by	KM
Checked by	MH/MT/CT

A303

WPI

Worcester Polytechnic Institute
100 Institute Rd.
Worcester, MA 01609

Design of AREN Building for WPI Campus



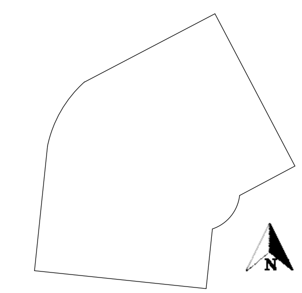
Design Documents

No.	Description	Date

Renderings

Scale	
Date	03/03/2016
Drawn by	MH
Checked by	KM/MT/CT

A901



Worcester Polytechnic Institute
100 Institute Rd.
Worcester, MA 01609

Design of AREN Building for WPI Campus

Design Documents

No.	Description	Date

Renderings

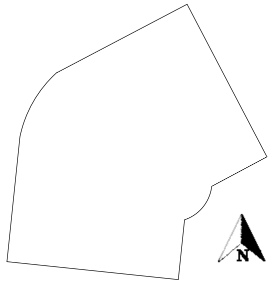
Scale	
Date	03/03/2016
Drawn by	MH
Checked by	Checker

A902

WPI

Worcester Polytechnic Institute
100 Institute Rd.
Worcester, MA 01609

Design of AREN Building for WPI Campus



Design Documents

No.	Description	Date

Renderings

Scale	
Date	03/03/2016
Drawn by	MH
Checked by	KM/MT/CT

A903

1 Level 1 - Lighting
1/16" = 1'-0"

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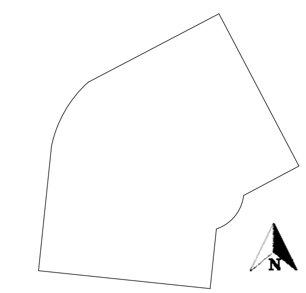
100 Institute Rd.
Worcester, MA 01609

Design of AREN Building for WPI Campus



Design Documents

No.	Description	Date

First Floor RCP

Scale	1/16" = 1'-0"
Date	03/03/2016
Drawn by	CLT/MCT
Checked by	KEM/MCH

E101

1 Level 2 - Lighting
1/16" = 1'-0"

WPI

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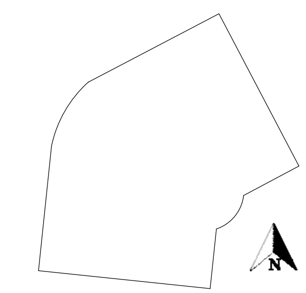
Design of AREN Building for WPI Campus



Design Documents

No.	Description	Date

Second Floor RCP

Scale	1/16" = 1'-0"
Date	03/03/2016
Drawn by	CLT/MCT
Checked by	KEM/MCH

E102

1 Level 3 - Lighting
1/16" = 1'-0"

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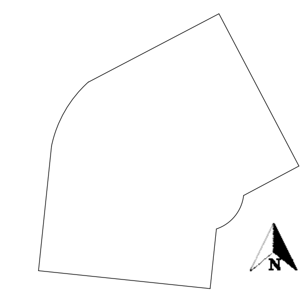
Design of AREN Building for WPI Campus



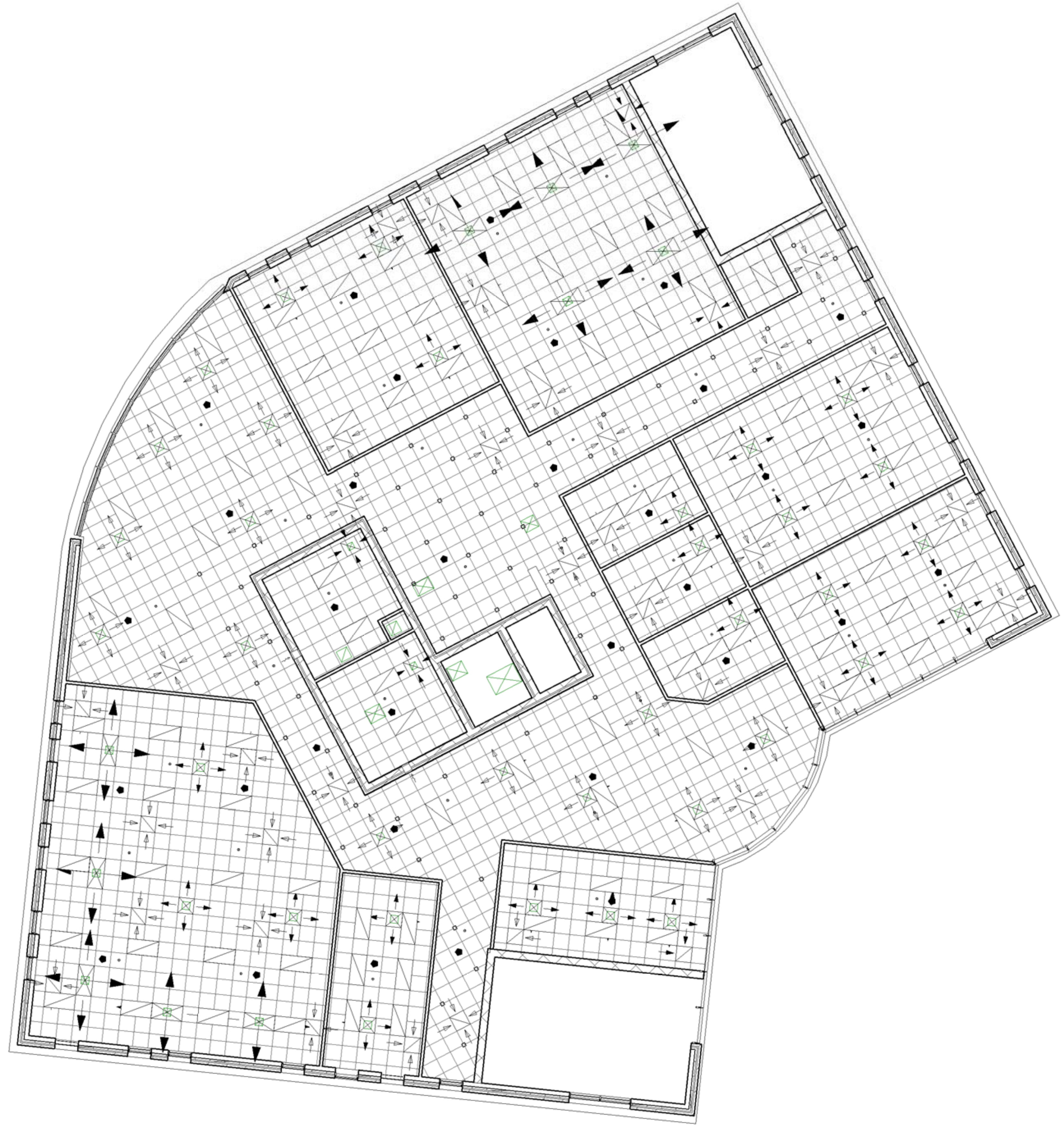
Design Documents

No.	Description	Date

Third Floor RCP

Scale	1/16" = 1'-0"
Date	03/03/2016
Drawn by	CLT/MCT
Checked by	KEM/MCH

E103



1 Level 4 - Lighting
1/16" = 1'-0"

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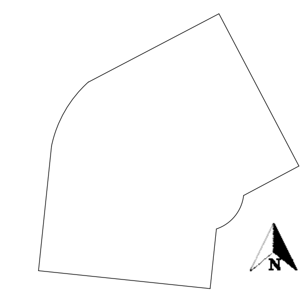
Worcester, MA 01609

Design of AREN Building for WPI Campus



Design Documents

No.	Description	Date

Fourth Floor RCP

Scale	1/16" = 1'-0"
Date	03/03/2016
Drawn by	CLT/MCT
Checked by	Checker

E104

1 Level 1 - Mechanical
1/16" = 1'-0"

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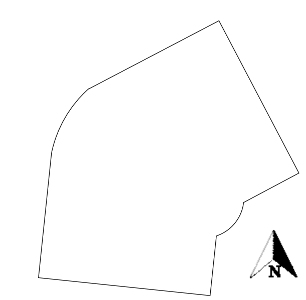
Design of AREN Building for WPI Campus



Design Documents

No.	Description	Date

First Floor RCP

Scale	1/16" = 1'-0"
Date	03/03/2016
Drawn by	CLT/MCT
Checked by	KEM/MCH

M101

1 Level 2 - Mechanical
1/16" = 1'-0"

WPI

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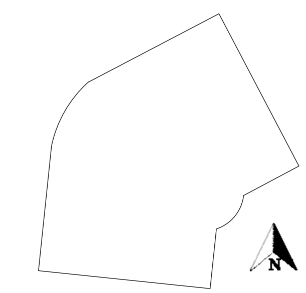
Design of AREN Building for WPI Campus



Design Documents

No.	Description	Date

Second Floor RCP

Scale	1/16" = 1'-0"
Date	03/03/2016
Drawn by	CLT/MCT
Checked by	KEM/MCH

M102

1 Level 3 - Mechanical
1/16" = 1'-0"

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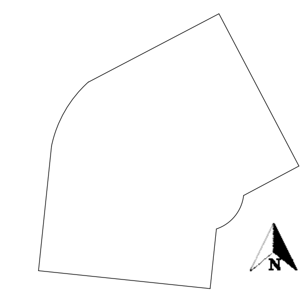
Design of AREN Building for WPI Campus



Design Documents

No.	Description	Date

Third Floor RCP

Scale	1/16" = 1'-0"
Date	03/03/2016
Drawn by	CLT/MCT
Checked by	KEM/MCH

M103

1 Level 4 - Mechanical
1/16" = 1'-0"

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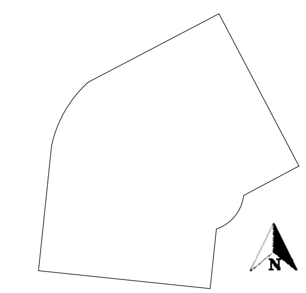
Design of AREN Building for WPI Campus



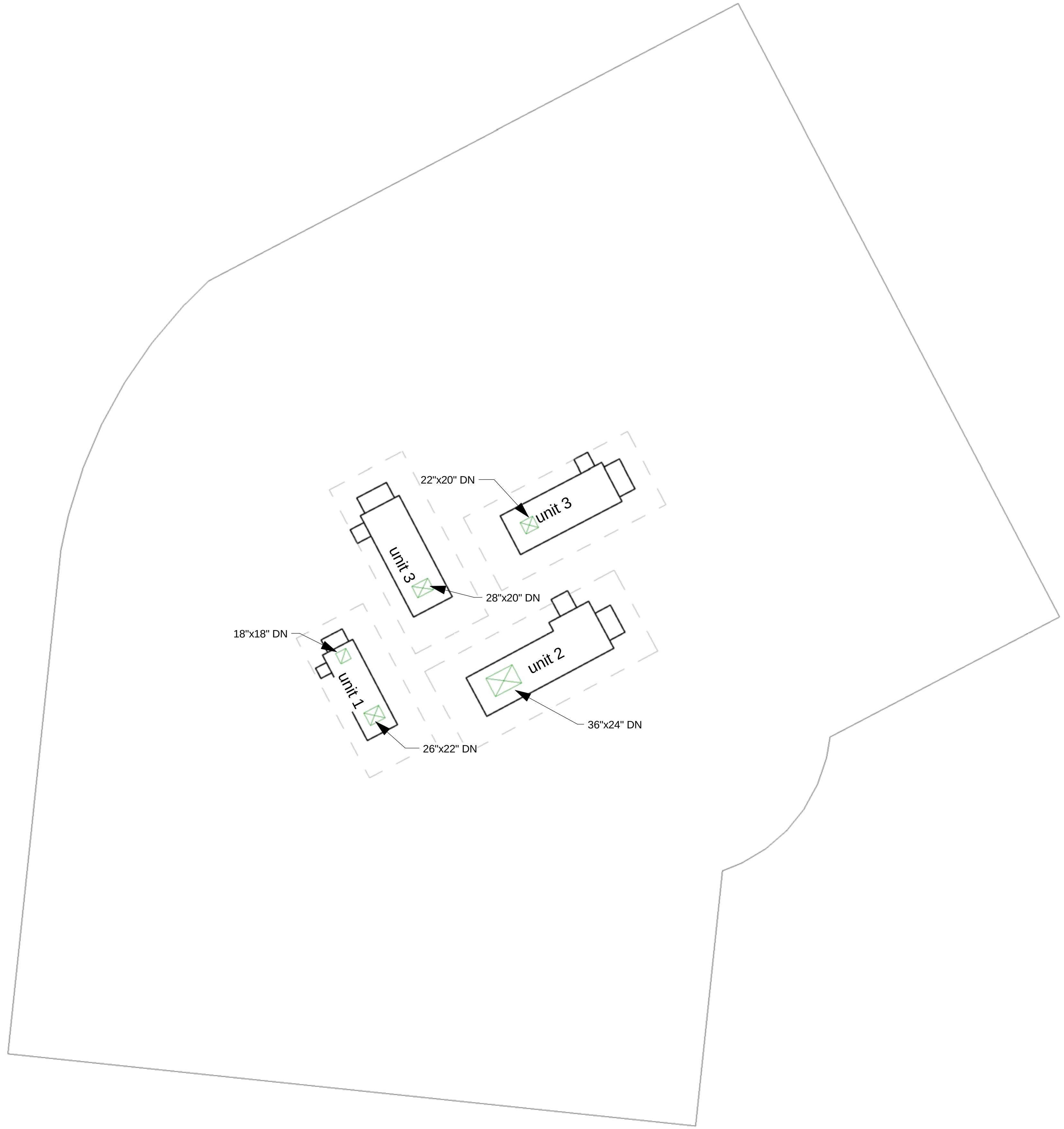
Design Documents

No.	Description	Date

Fourth Floor RCP

Scale	1/16" = 1'-0"
Date	03/03/2016
Drawn by	CLT/MCT
Checked by	KEM/MCH

M104



1 Roof
1/16" = 1'-0"

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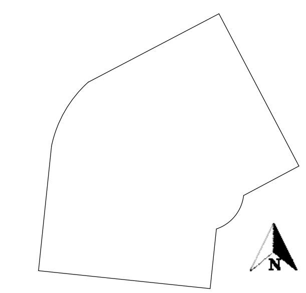
Design of AREN Building for WPI Campus



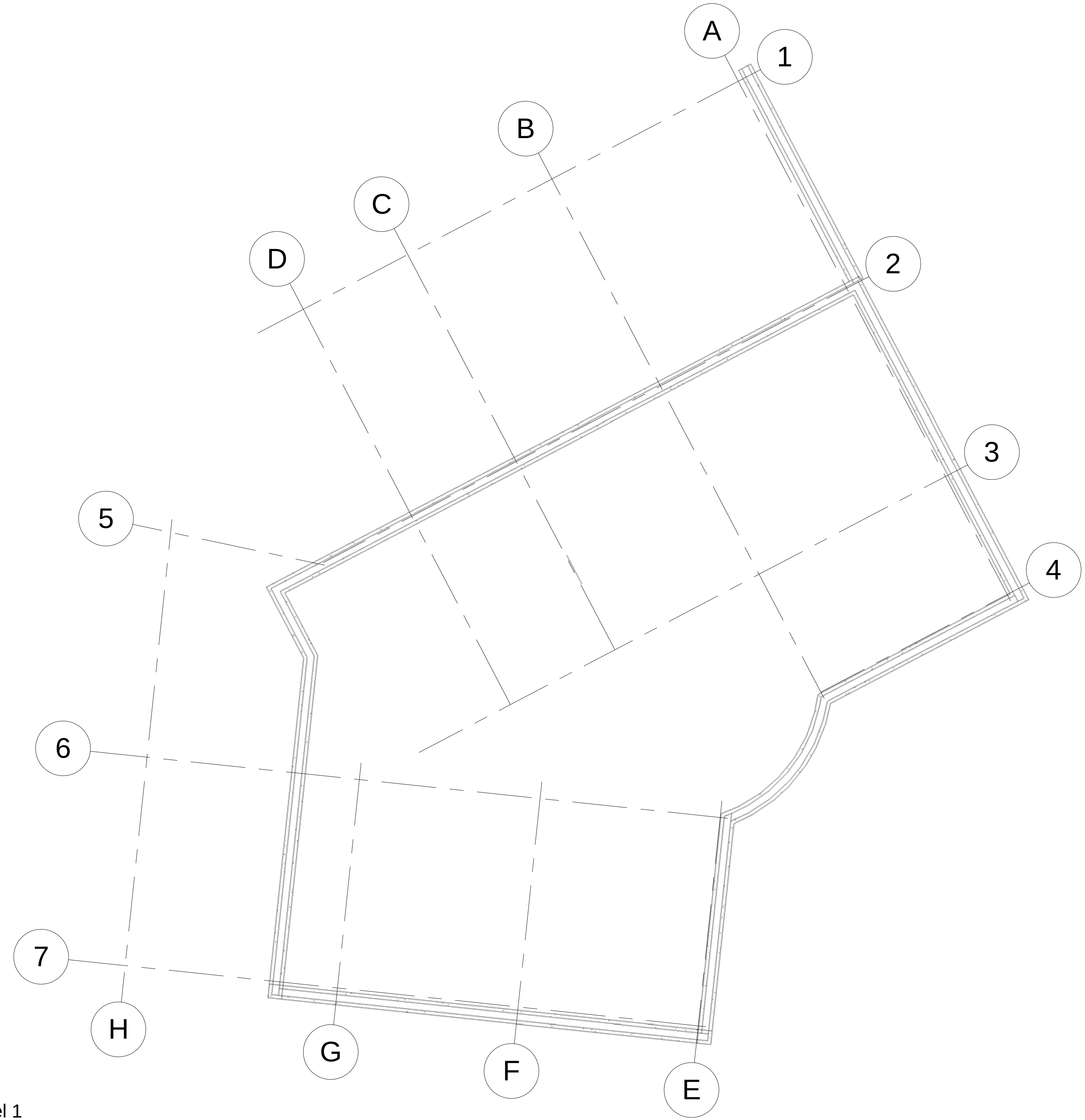
Design Documents

No.	Description	Date

Roof Plan

Scale	1/16" = 1'-0"
Date	03/03/2016
Drawn by	Author
Checked by	Checker

M105



1 Level 1
1/16" = 1'-0"

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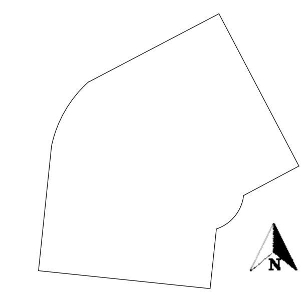
Worcester, MA 01609

Design of AREN Building for WPI Campus



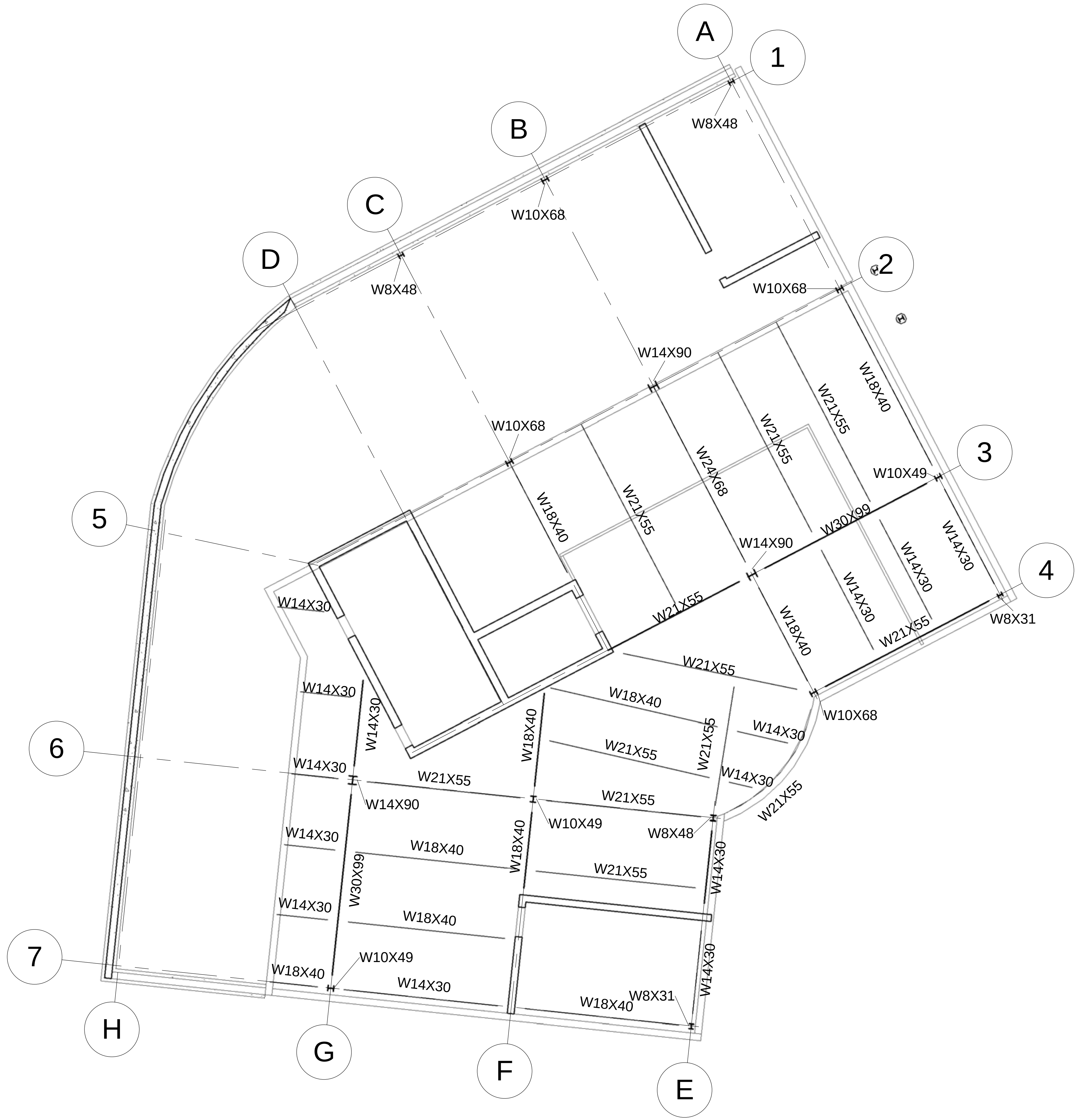
Design Documents

No.	Description	Date

First Floor Plan

Scale	1/16" = 1'-0"
Date	03/03/2016
Drawn by	KEM
Checked by	MCH, CLT, MCT

S101



1 Level 2
1/16" = 1'-0"

Worcester Polytechnic Institute
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Design of AREN Building for WPI Campus

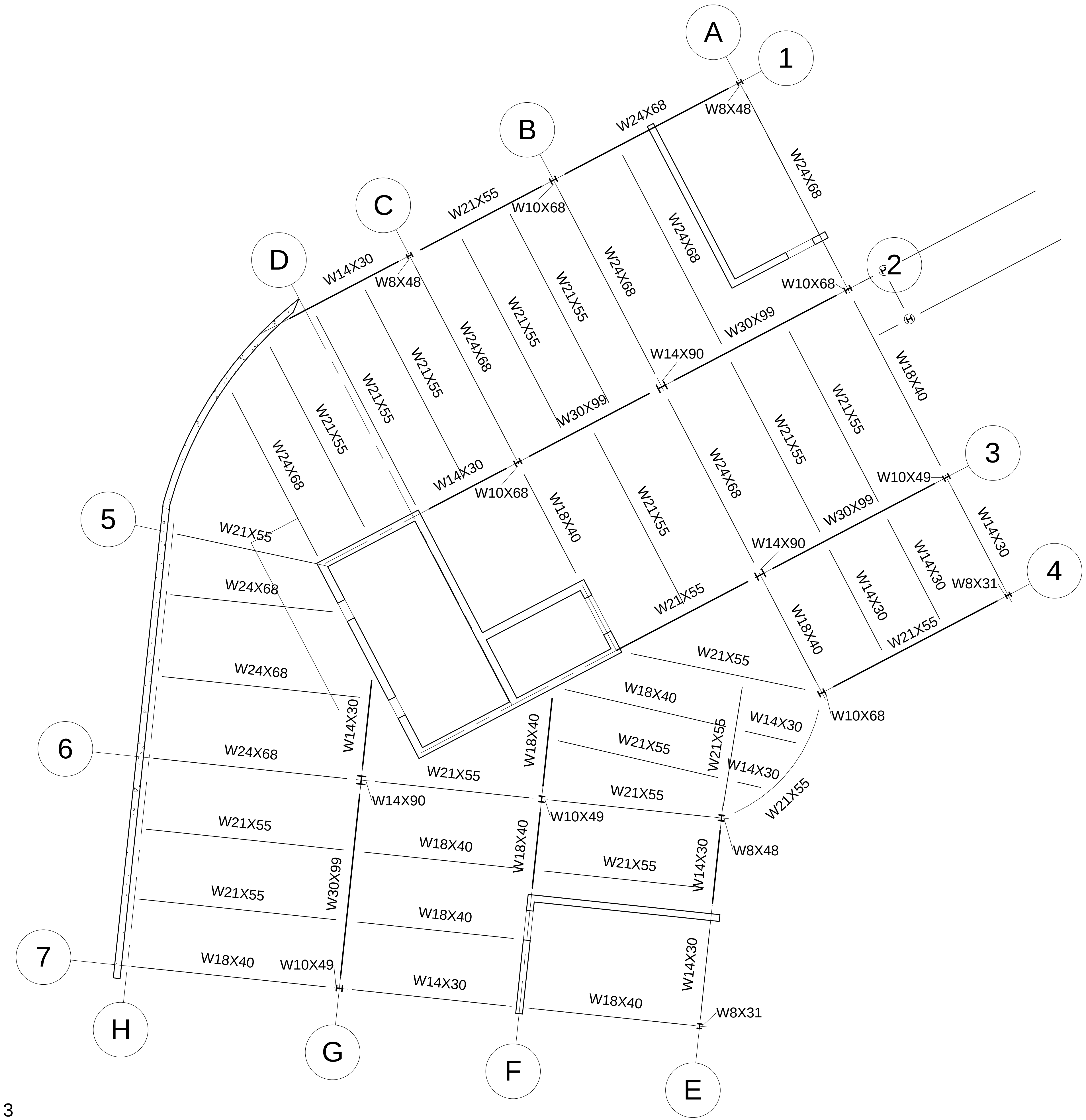
Design Documents

No.	Description	Date

Second Floor Plan

Scale	1/16" = 1'-0"
Date	03/03/2016
Drawn by	KEM
Checked by	MCH, CLT, MCT

S102



1 Level 3
1/16" = 1'-0"

WPI

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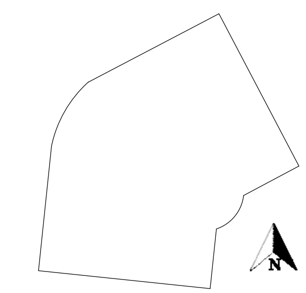
Design of AREN Building for WPI Campus



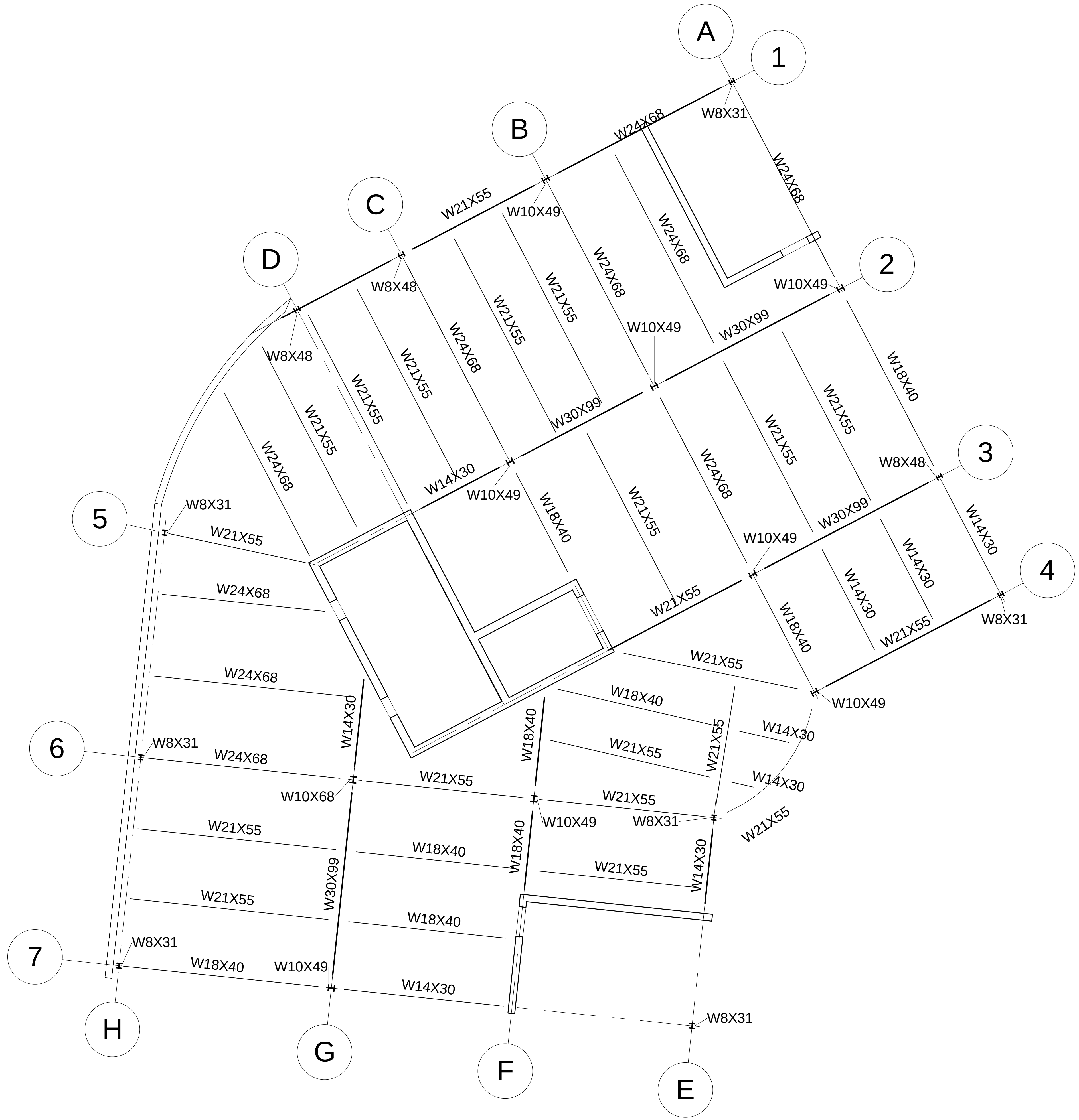
Design Documents

No.	Description	Date

Third Floor Plan

Scale	1/16" = 1'-0"
Date	03/03/2016
Drawn by	KEM
Checked by	MCH, CLT, MCT

S103



1 Level 4
1/16" = 1'-0"

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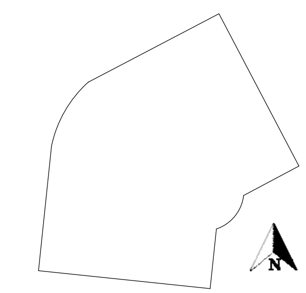
Design of AREN Building for WPI Campus



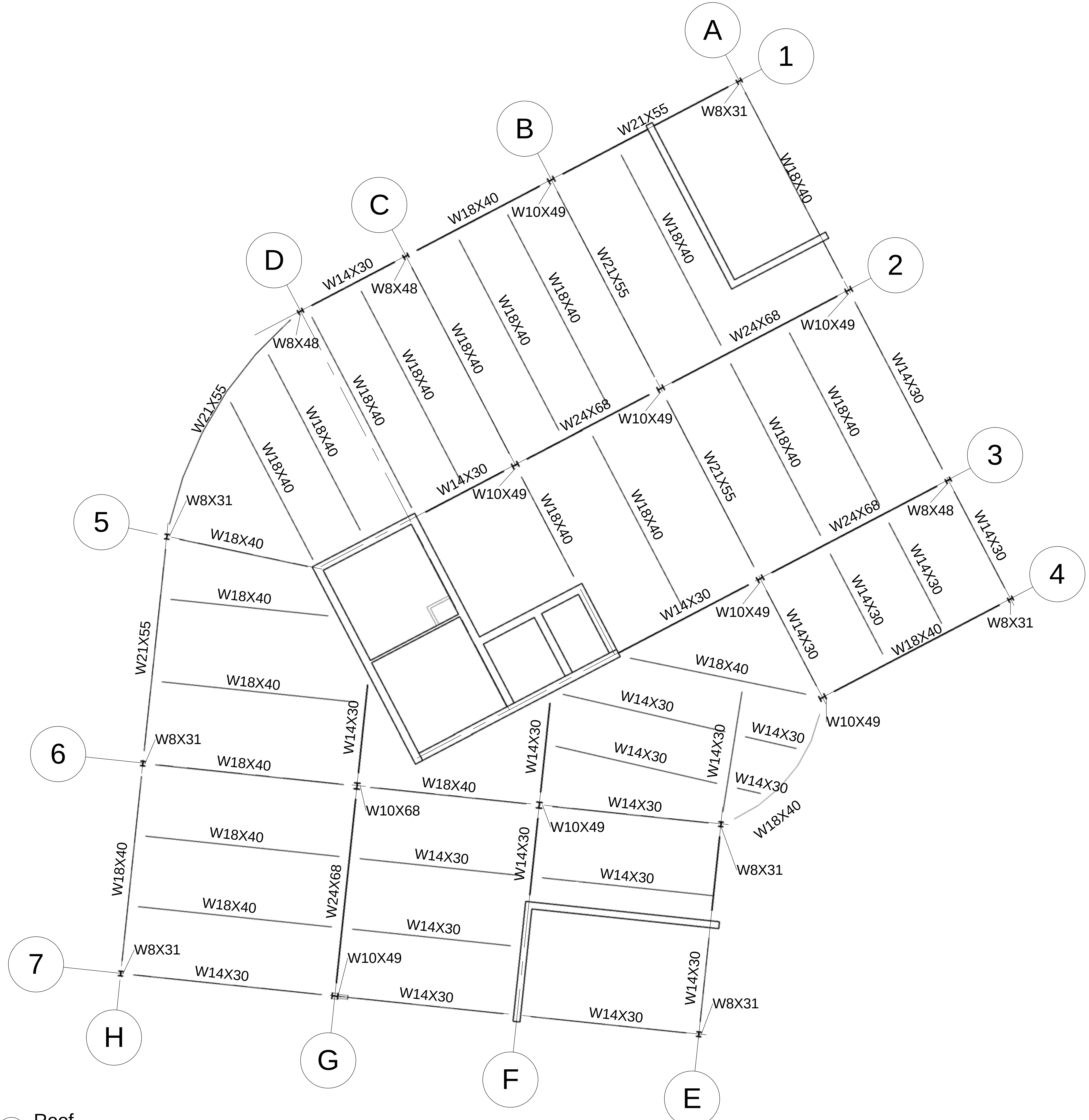
Design Documents

No.	Description	Date

Fourth Floor Plan

Scale	1/16" = 1'-0"
Date	03/03/2016
Drawn by	KEM
Checked by	MCH, CLT, MCT

S104



1 Roof
1/16" = 1'-0"

Worcester Polytechnic Institute
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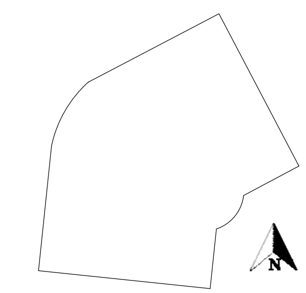
Design of AREN Building for WPI Campus



Design Documents

No.	Description	Date

Roof Plan

Scale	1/16" = 1'-0"
Date	03/03/2016
Drawn by	KEM
Checked by	MCH, CLT, MCT

S105

Structural Column Schedule						
Column Location Mark	Base Level	Top Level	Type	Weight	Length	Weight of Member
A(5' - 11 1/4")-2	Level 1	Level 3	W8X31	31	27' - 2 1/2"	843.46
A(5' - 11 1/4")-2(-8' - 0")	Level 1	Level 3	W8X31	31	27' - 2 1/2"	843.46
A-1	Level 2	Level 3	W8X48	48	16' - 10"	808.00
A-1	Level 3	Roof	W8X31	31	31' - 5 1/2"	975.21
A-2	Level 2	Level 3	W10X68	68	16' - 10"	1144.67
A-2	Level 3	Roof	W10X49	49	31' - 5 1/2"	1541.46
A-3	Level 1	Level 3	W10X49	49	30' - 8"	1502.67
A-3	Level 3	Roof	W8X48	48	31' - 5 1/2"	1510.00
A-4	Level 1	Level 3	W8X31	31	30' - 8"	950.67
A-4	Level 3	Roof	W8X31	31	31' - 5 1/2"	975.21
B-1	Level 2	Level 3	W10X68	68	16' - 10"	1144.67
B-1	Level 3	Roof	W10X49	49	31' - 5 1/2"	1541.46
B-2	Level 2	Level 3	W14X90	90	16' - 10"	1515.00
B-2	Level 3	Roof	W10X49	49	31' - 5 1/2"	1541.46
B-3	Level 3	Roof	W10X49	49	31' - 5 1/2"	1541.46
B-3	Level 1	Level 3	W14X90	90	30' - 8"	2760.00
B-4	Level 3	Roof	W10X49	49	31' - 5 1/2"	1541.46
B-4	Level 1	Level 3	W10X68	68	30' - 8"	2085.33
C-1	Level 2	Level 3	W8X48	48	16' - 10"	808.00
C-1	Level 3	Roof	W8X48	48	31' - 5 1/2"	1510.00
C-2	Level 2	Level 3	W10X68	68	16' - 10"	1144.67
C-2	Level 3	Roof	W10X49	49	31' - 5 1/2"	1541.46
D-1	Level 4	Roof	W8X48	48	17' - 1 1/2"	822.00
E-6	Level 2	Level 3	W10X49	49	13' - 10"	677.83
E-6	Level 3	Roof	W8X31	31	31' - 5 1/2"	975.21
E-6	Level 1	Level 3	W8X48	48	30' - 8"	1472.00
E-7	Level 1	Level 3	W8X31	31	30' - 8"	950.67
E-7	Level 3	Roof	W8X31	31	31' - 5 1/2"	975.21
F-6	Level 1	Level 3	W10X49	49	30' - 8"	1502.67
F-6	Level 3	Roof	W10X49	49	31' - 5 1/2"	1541.46
G-6	Level 3	Roof	W10X68	68	31' - 5 1/2"	2139.17
G-6	Level 1	Level 3	W14X90	90	30' - 8"	2760.00
G-7	Level 1	Level 3	W10X49	49	30' - 8"	1502.67
G-7	Level 3	Roof	W10X49	49	31' - 5 1/2"	1541.46
H-5	Level 4	Roof	W8X31	31	17' - 1 1/2"	530.88
H-6	Level 4	Roof	W8X31	31	17' - 1 1/2"	530.88
H-7	Level 4	Roof	W8X31	31	17' - 1 1/2"	530.88
Grand total: 37						48222.71

Structural Column Count	
Type	Count
W8X31	11
W8X48	6
W10X49	12
W10X68	5
W14X90	3
Grand total: 37	

Worcester Polytechnic Institute
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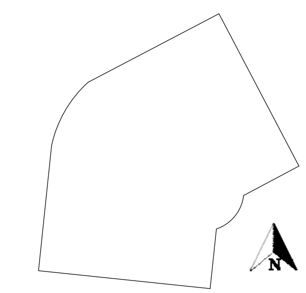
Design of AREN Building for WPI Campus



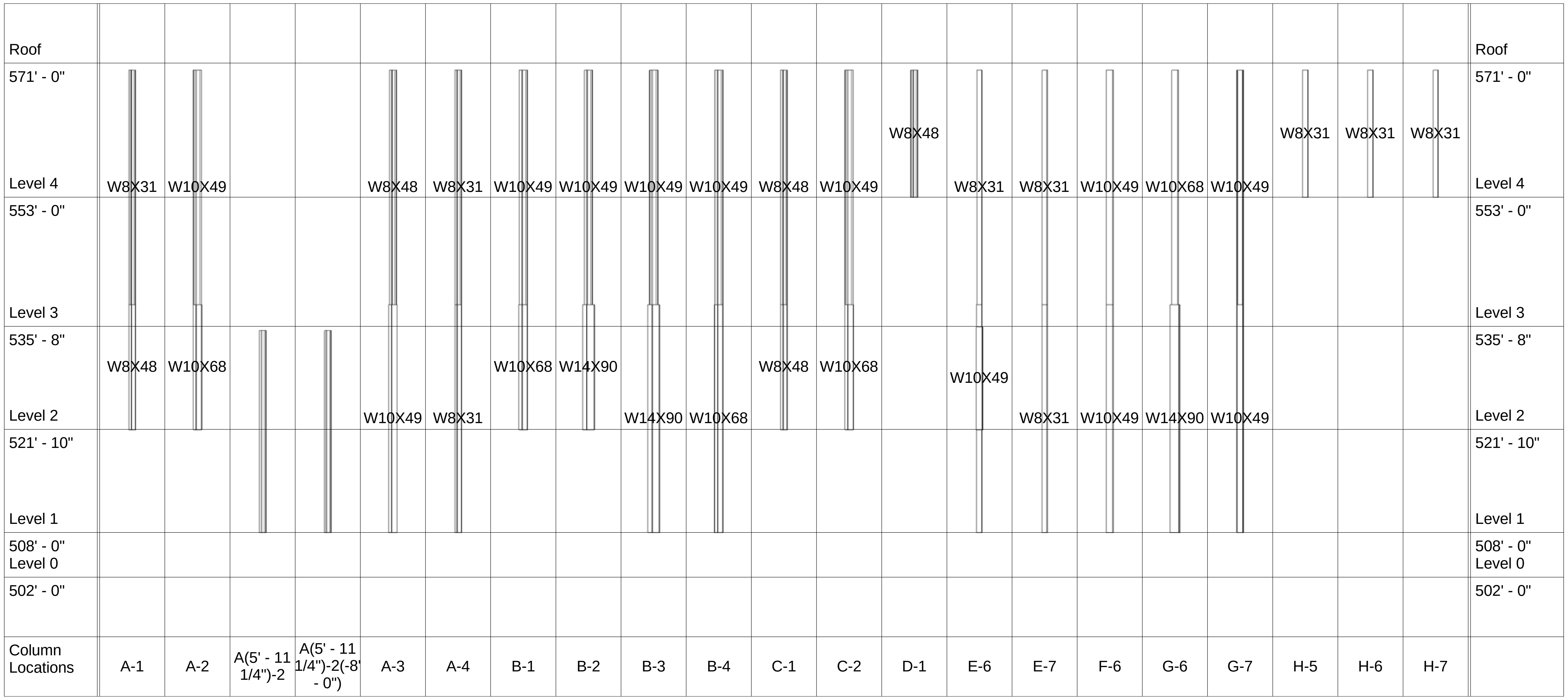
Design Documents

No.	Description	Date

Column Schedule

Scale	
Date	03/03/2016
Drawn by	KEM
Checked by	MCH, CLT, MCT

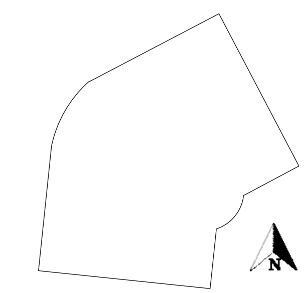
S600



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

Worcester Polytechnic Institute
100 Institute Rd.
Worcester, MA 01609

Design of AREN Building for WPI Campus



Design Documents

No.	Description	Date

Graphic Schedule

Scale	1/16" = 1'-0"
Date	03/03/2016
Drawn by	KEM
Checked by	MCH, CLT, MCT

S601

Structural Framing Schedule

Type	Length	Weight	Weight of Member
W30X99	31' - 0"	99	3069
W21X55	30' - 8"	55	1688
W30X99	30' - 8"	99	3039
W30X99	30' - 8"	99	3039
W14X30	14' - 7"	30	437
W30X99	23' - 9"	99	2350
W18X40	14' - 7"	40	582
W21X55	23' - 9"	55	1306
W14X30	17' - 8"	30	531
W14X30	16' - 8"	30	501
W21X55	24' - 9"	55	1362
W24X68	30' - 8"	68	2087
W21X55	23' - 9"	55	1306
W24X68	32' - 6"	68	2210
W18X40	32' - 6"	40	1300
W24X68	32' - 6"	68	2210
W24X68	28' - 0"	68	1902
W21X55	32' - 6"	55	1788
W21X55	32' - 6"	55	1788
W18X40	17' - 0"	40	680
W24X68	34' - 1"	68	2318
W24X68	34' - 1"	68	2318
W24X68	34' - 1"	68	2320
W18X40	31' - 0"	40	1240
W24X68	31' - 0"	68	2108
W14X30	19' - 5"	30	583
W18X40	19' - 5"	40	777
W21X55	26' - 6"	55	1458
W21X55	26' - 5"	55	1453
W14X30	26' - 6"	30	795
W18X40	26' - 5"	40	1057
W21X55	34' - 1"	55	1875
W21X55	23' - 8"	55	1303
W24X68	34' - 1"	68	2318
W21X55	34' - 1"	55	1875
W21X55	34' - 1"	55	1875
W24X68	30' - 5"	68	2070
W21X55	31' - 0"	55	1705
W14X30	19' - 5"	30	583
W21X55	31' - 0"	55	1705
W14X30	19' - 5"	30	583
W21X55	31' - 0"	55	1705
W18X40	26' - 6"	40	1060
W18X40	26' - 6"	40	1060
W21X55	26' - 5"	55	1453
W21X55	33' - 9"	55	1855
W21X55	30' - 8"	55	1688
W21X55	20' - 11"	55	1148
W18X40	28' - 0"	40	1119
W21X55	26' - 11"	55	1480
W21X55	33' - 5"	55	1839
W14X30	10' - 7"	30	318
W14X30	6' - 6"	30	196
W18X40	20' - 2"	40	808

Structural Framing Schedule

Type	Length	Weight	Weight of Member
W14X30	16' - 3"	30	488
W30X99	31' - 0"	99	3069
W21X55	30' - 9"	55	1690
W30X99	30' - 8"	99	3039
W14X30	14' - 7"	30	437
W18X40	14' - 7"	40	582
W21X55	23' - 9"	55	1306
W14X30	17' - 8"	30	531
W21X55	24' - 9"	55	1359
W14X30	8' - 11"	30	268
W18X40	8' - 11"	40	358
W14X30	8' - 11"	30	268
W14X30	9' - 0"	30	270
W14X30	8' - 11"	30	268
W14X30	8' - 11"	30	268
W18X40	17' - 0"	40	680
W18X40	31' - 0"	40	1240
W24X68	31' - 0"	68	2108
W14X30	19' - 5"	30	583
W18X40	19' - 5"	40	777
W21X55	26' - 6"	55	1458
W21X55	26' - 5"	55	1453
W14X30	26' - 6"	30	795
W18X40	26' - 5"	40	1057
W21X55	31' - 0"	55	1705
W14X30	19' - 5"	30	583
W21X55	31' - 0"	55	1705
W14X30	19' - 5"	30	583
W21X55	31' - 0"	55	1705
W18X40	26' - 6"	40	1060
W18X40	26' - 6"	40	1060
W21X55	26' - 5"	55	1453
W21X55	30' - 8"	55	1686
W21X55	20' - 10"	55	1148
W18X40	28' - 0"	40	1119
W21X55	26' - 11"	55	1480
W14X30	10' - 7"	30	317
W14X30	6' - 6"	30	195
W18X40	20' - 2"	40	808
W14X30	16' - 0"	30	480
W30X99	30' - 1"	99	2978
W21X55	30' - 9"	55	1690
W30X99	30' - 8"	99	3039
W30X99	30' - 8"	99	3039
W14X30	14' - 7"	30	437
W30X99	23' - 9"	99	2350
W18X40	14' - 7"	40	582
W21X55	23' - 9"	55	1306
W14X30	17' - 8"	30	531
W14X30	16' - 8"	30	501
W21X55	24' - 9"	55	1359
W24X68	30' - 9"	68	2091
W21X55	23' - 9"	55	1306
W14X30	23' - 1"	30	692

Structural Framing Schedule

Type	Length	Weight	Weight of Member
W24X68	32' - 6"	68	2210
W18X40	32' - 6"	40	1300
W24X68	32' - 6"	68	2210
W24X68	28' - 0"	68	1902
W21X55	32' - 6"	55	1788
W21X55	32' - 6"	55	1788
W18X40	17' - 0"	40	680
W24X68	34' - 1"	68	2318
W24X68	34' - 1"	68	2318
W24X68	34' - 1"	68	2318
W18X40	31' - 0"	40	1240
W24X68	31' - 0"	68	2108
W14X30	19' - 5"	30	583
W18X40	19' - 5"	40	777
W21X55	26' - 6"	55	1458
W21X55	26' - 5"	55	1453
W14X30	26' - 6"	30	795
W18X40	26' - 5"	40	1057
W21X55	34' - 1"	55	1875
W21X55	23' - 8"	55	1303
W24X68	34' - 1"	68	2318
W21X55	34' - 1"	55	1875
W21X55	34' - 1"	55	1875
W24X68	30' - 5"	68	2070
W21X55	31' - 0"	55	1705
W14X30	19' - 5"	30	583
W21X55	31' - 0"	55	1705
W14X30	19' - 5"	30	583
W21X55	31' - 0"	55	1705
W18X40	26' - 6"	40	1060
W18X40	26' - 6"	40	1060
W21X55	26' - 5"	55	1453
W21X55	33' - 9"	55	1855
W21X55	30' - 8"	55	1686
W21X55	20' - 10"	55	1148
W18X40	28' - 0"	40	1119
W21X55	26' - 11"	55	1480
W21X55	34' - 1"	55	1875
W14X30	10' - 7"	30	317
W14X30	6' - 6"	30	195
W18X40	20' - 2"	40	808
W14X30	16' - 0"	30	480
W24X68	31' - 0"	68	2108
W18X40	30' - 8"	40	1228
W24X68	30' - 8"	68	2087
W24X68	30' - 8"	68	2087
W14X30	14' - 7"	30	437
W24X68	23' - 9"	68	1614
W14X30	14' - 7"	30	437
W14X30	23' - 9"	30	713
W14X30	17' - 8"	30	531
W14X30	16' - 8"	30	501
W18X40	24' - 9"	40	990
W21X55	30' - 8"	55	1688

Structural Framing Schedule

Type	Length	Weight	Weight of Member
W18X40	23' - 9"	40	950
W14X30	17' - 2"	30	516
W18X40	31' - 2"	40	1246
W14X30	31' - 2"	30	935
W18X40	31' - 2"	40	1245
W18X40	26' - 7"	40	1064
W18X40	31' - 2"	40	1246
W18X40	31' - 2"	40	1246
W14X30	17' - 0"	30	510
W21X55	34' - 1"	55	1875
W18X40	34' - 1"	40	1363
W18X40	34' - 1"	40	1365
W14X30	31' - 0"	30	930
W21X55	31' - 0"	55	1705
W14X30	19' - 5"	30	583
W14X30	19' - 5"	30	583
W18X40	26' - 6"	40	1060
W14X30	26' - 5"	30	793
W14X30	26' - 4"	30	790
W14X30	26' - 6"	30	795
W18X40	34' - 1"	40	1363
W18X40	22' - 3"	40	891
W18X40	34' - 1"	40	1364
W18X40	34' - 1"	40	1363
W18X40	34' - 1"	40	1363
W18X40	28' - 8"	40	1146
W18X40	31' - 0"	40	1240
W14X30	19' - 5"	30	583
W18X40	31' - 0"	40	1240
W14X30	19' - 5"	30	583
W18X40	31' - 0"	40	1240
W14X30	26' - 6"	30	795
W14X30	26' - 6"	30	795
W14X30	26' - 5"	30	793
W18X40	32' - 2"	40	1287
W18X40	30' - 8"	40	1227
W14X30	20' - 11"	30	626
W14X30	28' - 0"	30	840
W14X30	26' - 11"	30	808
W18X40	34' - 1"	40	1363
W14X30	10' - 7"	30	317
W14X30	6' - 6"	30	195
W18X40	20' - 2"	40	808
W14X30	16' - 0"	30	481
W21X55	38' - 8"	55	2126
W21X55	33' - 0"	55	1813
W18X40	30' - 8"	40	1226
W14X30	8' - 0"	30	240
W14X30	25' - 0"	30	750
W14X30	25' - 0"	30	750
W14X30	5' - 11"	30	178
W14X30	5' - 0"	30	150
W14X30	23' - 1"	30	692
Grand total: 215			270847

Structural Framing Totals

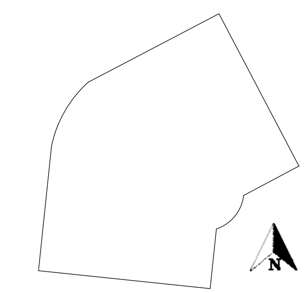
Type	Count
W14X30	66
W18X40	55
W21X55	59
W24X68	25
W30X99	10

Grand total: 215

WPI

Worcester Polytechnic Institute
100 Institute Rd.
Worcester, MA 01609

Design of AREN Building for WPI Campus



Design Documents

No.	Description	Date

Framing Schedule

Scale	
Date	03/03/2016
Drawn by	KEM
Checked by	MCH, CLT, MCT

S602