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Renovation of the Kaven Hall Attic

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Abstract

The goal of this project was to propose a renovation to the Attic of Kaven Hall which would transform the unfinished space into usable space for the Civil and Environmental Engineering Department. In order to do this the existing conditions were evaluated, applicable building codes were researched, and surveys were administered. From there, a floor plan and structural changes were developed using AutoCAD. Finally, a cost estimate and a construction schedule were formulated for the proposed renovation.

Authorship

Contribution

Introduction……………………………………………….Chad Farrell, Elizabeth McLaughlin,
Sean Kennedy

Existing Conditions……………………………………….Chad Farrell, Elizabeth McLaughlin

Code Compliance…………………………………………Sean Kennedy

Proposed Plan……………………………………………..Chad Farrell

Structural Design and Analysis…………………………...Sean Kennedy

Project Scheduling and Cost Estimation………………….Elizabeth McLaughlin

Conclusions and Recommendations……………………...Sean Kennedy, Chad Farrell

Additional Work

AutoCAD Drawings……………………………………...Elizabeth McLaughlin, Sean Kennedy

Photos…………………………………………………….Chad Farrell

Survey…………………………………………………….Elizabeth McLaughlin, Sean Kennedy
Chad Farrell

Stair Design……………………………………………….Elizabeth McLaughlin

Elevator Design…………………………………………...Chad Farrell

Roof Design……………………………………………….Sean Kennedy

Dormer Design…………………………………………….Sean Kennedy

Skylight Design…………………………………………...Sean Kennedy

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1 Introduction

Kaven Hall currently resides on the Northeast corner of the WPI campus and hosts the Civil and Environmental Department. It was constructed in 1954 with four floors: a basement, first floor, second floor, and an attic. Located in the basement are the various laboratories needed by the CEE Department used for structural engineering, environmental engineering, geotechnical engineering, and construction materials. The first floor consists of a lecture hall, a smaller classroom, a surveying equipment storage room, a conference room, assorted professor and teaching assistant offices, a lounge for the students, and a coffee/copy room for the faculty. The second floor contains one graduate classroom, a graduate research room, two computer labs and more faculty offices. The attic is very different from the other floors, as it is unfinished and used primarily for storage. The majority of the items currently being stored there is old papers and projects and outdated literature and equipment.

Much has been said about the need for additional space in Kaven Hall. Additional office space for professors and teaching assistants is desired, as is a conference room for larger groups of students and/or professors and smaller meeting rooms similar to the tech suites available in WPI's Gordon Library. Another classroom would be beneficial to both the students and faculty of the CEE Department, as would additional lounge space for students to relax before and after rigorous classes.

The available space for the renovation in Kaven Hall it is extremely limited and therefore limits what the space can be used for. Kaven Hall is an old building and since its erection 54 years ago, the only major renovation to the building has been that of the basement, where old laboratories were upgraded and new laboratories were created. Since the rest of the building is already completely occupied, the unfinished attic is the best location for a space increasing renovation.

1.1 Reasons for Renovation

The reasons for renovating a building vary based on the needs of the people who use it. In order to decide what should be included in the renovation of Kaven Hall's attic, the needs of the faculty and students of the CEE department needed to be researched. One suggested way to do this was through a survey. Since the needs of students are different from the needs of faculty, two surveys were created and then e-mailed out to the students and faculty of the CEE Department. The surveys listed several practical and feasible uses of the space that could be created by the attic's renovation and can be found in Appendices A1 (students) and A2 (faculty). The recipients of the survey were given five to seven options, depending on which survey, and were asked to rank each idea from one to five, or seven, with 1 being the most necessary. The results of the surveys were then used to divide up the available space in the attic and develop a floor plan and can be found in Appendices A3 (students) and A4 (faculty).

Any renovation to the Kaven Hall attic seems like a great idea when end result is considered, but there are several obstacles which also need to be considered. For one, the attic is not up to the current specifications of the Code of Massachusetts Regulations (CMR) or the American Disability Act (ADA). Since any renovation in excess of $100,000 to the building would need to comply with both sets of codes, the attic would need to be made handicap accessible and ceilings would need to be a minimum of 8' high amongst other things. This creates a need for the construction of two stairway exits, the installation of an elevator, as well as the installation of dormers. The renovation must also be structurally and financially feasible if its execution is to be considered by WPI.

The other significant obstacle in renovating the attic is its existing condition. Currently, the attic is home to an ever-growing collection of old projects and papers and outdated books and equipment. If the space in the attic were to be renovated, its current content would need to be sorted and relocated, if not discarded. The existing slant of the roof limits the amount of available space which can be occupied by people, leaving an ample amount of unoccupiable space which could be used for storage. This way, the renovation would include only a minor relocation of the stored materials.

In order to get a general idea of where to begin and the path to follow in planning the renovation, previous MQPs on the topic were reviewed. There were three MQPs to examine; *Kaven Hall* by Lonn F. Beaudin; *The Renovation of the Kaven Hall Attic* by Tim Fox, Paul Elliot, and Matt Brodeur; and *Air Conditioning Kaven Hall* by David C. MacGregor. A brief summary of what was learned from these MQPs was developed soon after.

1.2 Analysis of Previous MQPs

The MQP "Kaven Hall" written in May 1995 by Lonn F. Beaudin dealt with the proposal of a construction and renovation process that would occur in Kaven Hall. The main objective of the report was to find a schedule in which the building could still be partially used while undergoing construction. Two case studies were analyzed in this MQP. One dealt with the constraints that may impact a renovation project of an occupied building. The other study dealt with a project executed by WPI on the Higgins Laboratories. In addition to these two case studies, there were two individuals from Cutler Associates of Worcester who were interviewed in regards to the Kaven Hall renovation project. The first interview discussed meeting the needs of the users of the building undergoing renovation, while the other interview was geared towards learning about the phasing of a renovation process.

The renovation that Lonn proposed was a 10,000 square foot addition that was to be added onto the southwest corner of the existing building. After drawing out his renovation plans, Lonn had to decide what to do with the teachers whose offices could no longer be used, because of the current renovation. He then devised a plan so that they could still carry out their everyday activities. Something that seemed to cause problems was the storing of materials needed for construction. He had to deal with this problem, and realized that there needed to be a place to store all the equipment and materials that were currently in the attic. Although he does not go through the description of designing the attic, he does present what needs to be done for the construction of the attic. He devised a construction schedule in such a way that the work is scheduled around WPI classes. One thing he did not realize until the end is that MQP groups will not be able to use the labs at all times. Even though Lonn did not describe any designs or show exactly how he would renovate the attic, he did describe the process that would occur in order to do these things.

In 1997, David MacGregor proposed the addition of a HVAC system to be installed in Kaven Hall. This MQP was named: Air Conditioning in Kaven Hall. The MQP was prepared with a few things in mind: to design an economical solution and conform to applicable codes set forth by the *CMR* while avoiding the addition of equipment which could not be supporting by the existing central power plant. Other objectives of this MQP included the research of an updated mechanical system including a cost estimate and operating cost of the designed HVAC system.

In order to do all this, a number of steps and procedures were followed. Step number one was the gathering of physical information about the building such as the size, height, and area. The second step was to determine the thermal properties of the various building components. The third step was to design outdoor weather conditions, and choose the appropriate values from data compiled in ASHRAE 1993 Fundamentals Handbook. The next step was to determine the allowable interior design conditions per the *CMR*. After that was done, the design heating load had to be found by calculating the sum of heat losses through solid exterior surfaces and the heat loss due to the infiltration of outside air.

The next step was determining the design conditions. These conditions include the occupancy load and pattern, lighting quantities, hours of use, equipment, and the equipment hours of operation. Step seven was to determine the cooling load for the entire building using two different methods; the Residential Method and the CLTD/SCLCLF (Cooling Load Temperature Difference/Solar Cooling Load/Cooling Load Factor) Method. The next step in this procedure was to investigate the different types of heating and cooling systems. Then the individual room load had to be calculated in order to size the fan coils. Using this information, fan coils were selected for each space, and with the fan coils selected, the pipe sizes could be designed. The final step was to prepare a cost estimate.

After much research and calculations, the best system was selected for use in Kaven Hall. This system is known as a two-pipe, all water system that would provide heating, cooling and ventilation for all classrooms, computer labs, and basement labs located within Kaven Hall. Heat would be provided by steam from the central steam plant, and then converted into hot water in a heat exchanger. Cooling, on the other hand, would come from chilled water that would be provided by compressors mounted on the outside building wall or by an air-cooled chiller. The hot or chilled water would be distributed by a pump in the basement of Kaven Hall to fan-coil units located in each conditioned space. These fan-coils would draw outside air into the building through louvers with motorized dampers, and will condensate drain pans and trapped drains.

Additionally, each room would be controlled by its own thermostat. Energy controls would allow the fan-coils to increase the amount of outside air to the room when the outside air temperature allows free heating or cooling. The final cost estimate for this HVAC mechanical system was $480,210.

The last MQP regarding Kaven Hall was that of Corey M. Brodeur, Paul C. Elliot and Timothy J. Fox written in 2003 and titled: Renovation of the Kaven Hall Attic. This report begins by explaining the need for more space in Kaven Hall, and reasons why renovating the attic would be beneficial. The group states that using existing space more effectively, is one of the most cost effective means of increasing the amount of usable space.

The group began by surveying the attic. They determined the nature of all structural materials, the dimensions of floors, roofs, beams, mechanical equipment, and any other permanent structures affecting the layout and usability of the space. They also took an inventory of the attic, after which, it was determined that most of the things being stored there could be discarded or stored in a more consolidated manner.

Once the available space was established, the group examined the Code of Massachusetts Regulations (CMR) and the Americans with Disabilities Act (ADA). This was done to determine what rules and regulations would need to be followed. These standards were then considered along with the results of two surveys given to faculty and students, respectively. These surveys were developed in order to determine the need for different types of spaces. The results of these surveys concluded that group meeting and help session space were the most desired. All of this information was used to develop two possible floor plans for the renovation of the attic.

Both scenarios included a large amount of lounge space, and smaller rooms for meetings, conferences, studying, men's and women's bathrooms, and plenty of storage space in the areas with low ceiling heights. Both layouts included the installation of skylights and dormers for natural sunlight and ventilation. Design calculations were performed to ensure that the building could withstand the proposed renovations, and that the current mechanical systems could support the proposed changes. In addition, design calculations were also performed to determine the size and types of materials necessary for the construction of: new walls, dormers, stairwells, an elevator and any other materials necessary for renovation.

Lastly, the project schedule and cost estimate were determined. Using Primavera, the renovations were estimated to take approximately 176 days to complete. The cost of the proposed renovations was estimated to be approximately $980,000 in 2003.

1.3 Intent of This MQP

This MQP has the primary goal of proposing a renovation of Kaven Hall's attic with the needs of the faculty and students of the CEE Department in mind. As a byproduct of this renovation, the attic of Kaven Hall was designed to be code compliant and accessible to all persons including the physically handicapped. All alterations and construction completed were designed according to the *CMR* and *ADA* code, and feasibility of the objective. The renovation was proposed with the most cost and time effective schedule in mind.

The first step in the renovation process was to establish an appropriate understanding of the existing conditions. The attic was visited and surveyed several times in order to get a sufficient description. All fixed items and permanent structures were identified and quantified. After that, the roof structures and characteristics were studied. Finally, with the information collected, an accurate representation was developed with the use of AutoCAD.

With the existing conditions determined, all applicable codes had to be reviewed and included in the report. The applicable codes came from the Massachusetts Building Code from the Code of Massachusetts Regulations and from the Americans with Disabilities Act. These codes set standards for any construction to be completed to existing buildings. Since work was to be done to the attic, the attic then had to be compliant with both codes. This meant that it had to be accessible to all persons, bathrooms, proper lighting, and ventilation had to be installed, along with acceptable finishes and insulation. All work proposed had to be done as to not stray from the standards set forth in both the *ADA* and *CMR*.

After the proposal was completed, calculations had to be computed in order to determine structural properties of the attic. Properties such as the strength and weight of the roof, along with the composition and yield strength of the concrete floor slab. These characteristics had to be determined in order to design all additions and installations. Among the items that had to be designed were: dormers, staircases, and an elevator shaft. In addition heat loss, as well as the required amount of ventilation and lighting, was calculated.

Finally, with all design work done and the proposed plan finalized, all activities of the project had to be quantified. These activities were then assigned dollar values and time durations. These dollar values and time durations were then used to complete an accurate cost estimate and project schedule respectively.

2 Existing Conditions

The first goal entering this project was to review the previous MQPs to get a general idea of what was ahead. Once this was completed, the next step was to contact WPI Facilities in order to schedule a meeting to view the floor plans for Kaven Hall in the basement of their office (27 Hackfeld Street). From there the outer dimensions of the building and the dimensions of the stairwell were determined. These dimensions made it possible to develop the start of an accurate floor plan, which can be seen in Figure 2.1, using AutoCAD. The next step was to visit the attic to survey the existing conditions.

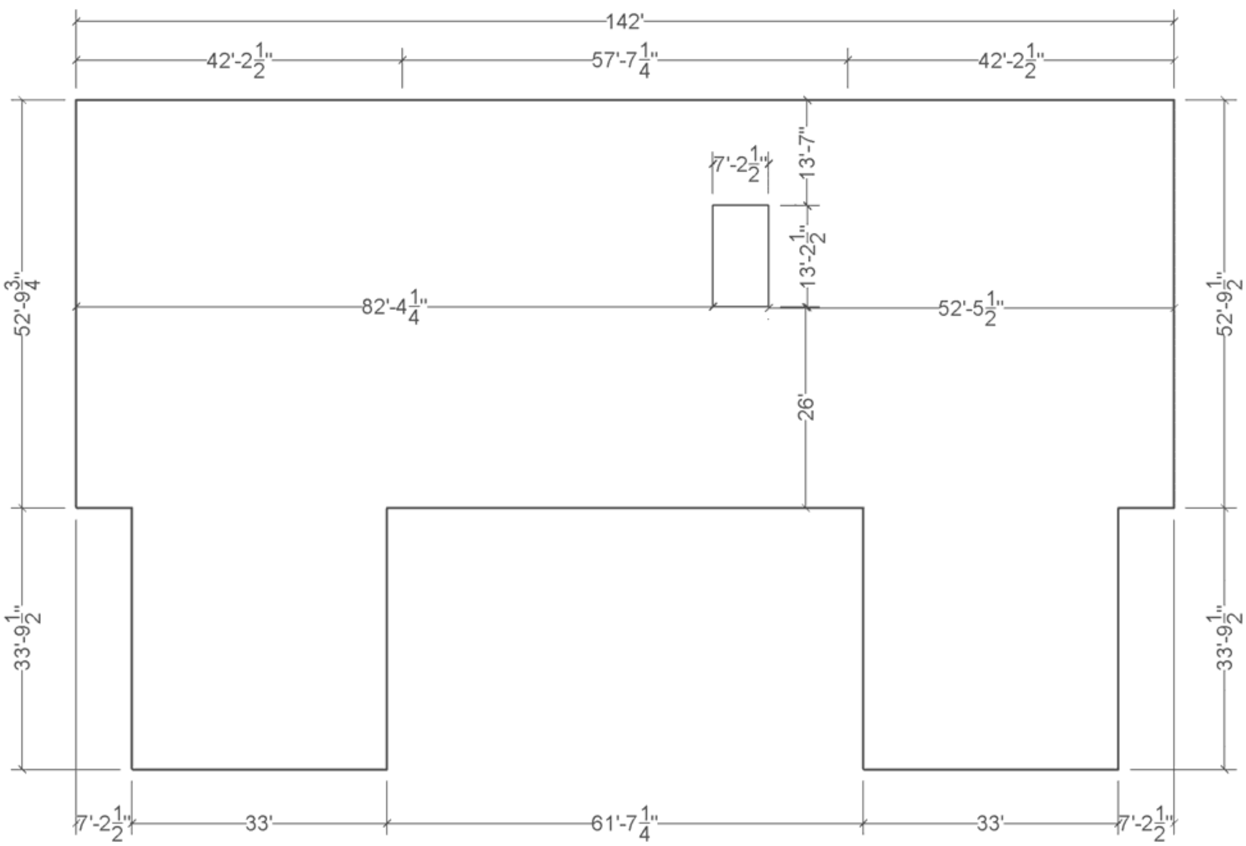


Figure 2.1 Existing Floor Plan

A visit to the attic revealed that it is divided into three sections by two walls which run the width of the building. The only entrance to the attic (from the stairs located on the second floor behind a door labeled "205") opens into the main/center room. On either side of this room are identical rooms, each with an extension. These rooms will be referred to as Section 1, Section 2 and Section 3 in accordance with the labels in Figure 2.2. Section 1 and 3 contain the majority of the old MQP projects, outdated text books, rocks used for Geology, old surveying equipment, boxes of papers and reports, old chairs and desks and also computer equipment. Many of these paper items are arranged on metal bookshelves, while the other items are scattered throughout the rooms with no visible organization. Most of these materials can be discarded and thrown away because they are out of date and unusable and those which cannot be discarded can be stored in a more organized fashion. Part of the center room of the attic is also home to large quantity of similar items.

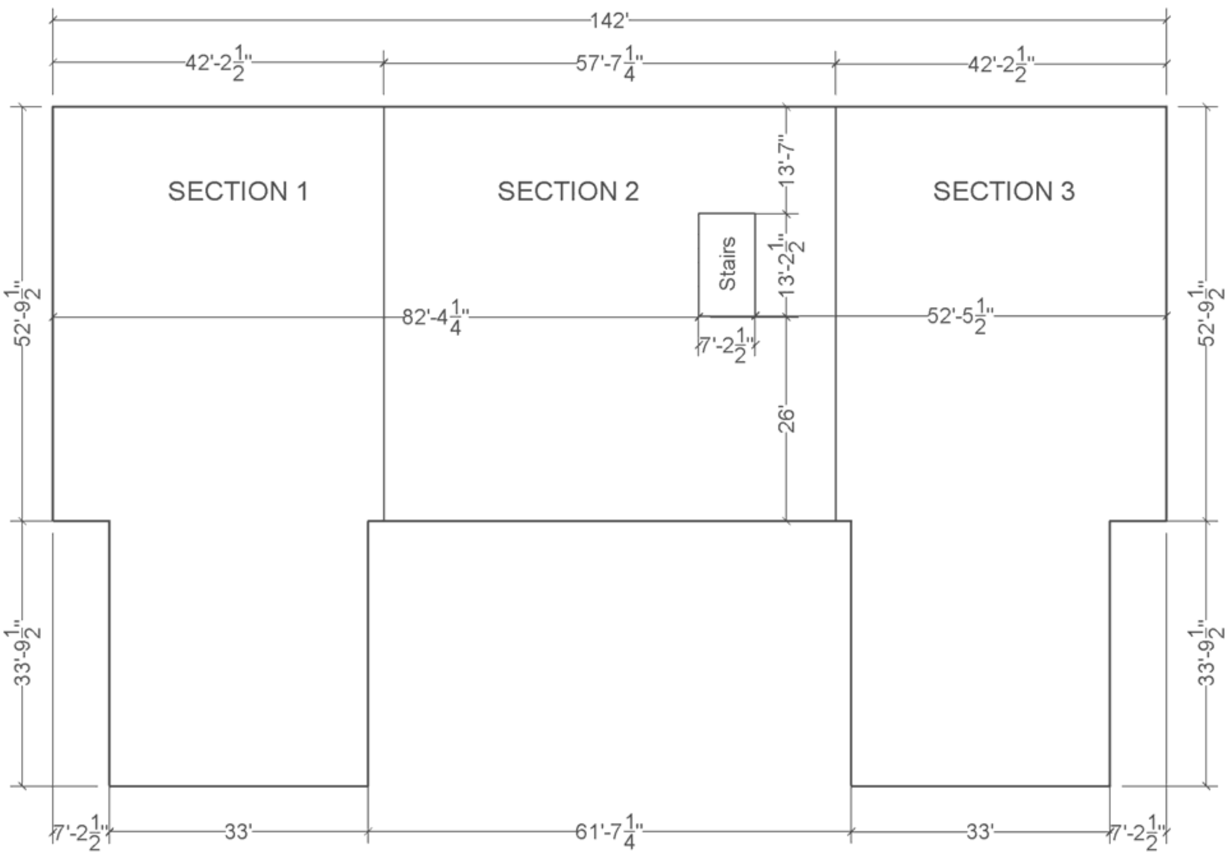


Figure 2.2 Existing Walls and Sections

2.1 Floor Analysis

Upon observation, it is clear that the floor in the attic is a concrete slab. By visually inspecting the slab from different places throughout Kaven Hall, particularly in the stairwell that leads to the attic, it is to be assumed that the current concrete floor slab is a waffle slab with rebar in each of the stems, and in the face of the slab. The total dead load of the slab was calculated to be 75psf which factors in the slab, floor finish, and lighting. The total design live load of an institutional building is 100 psf. Using the factored loading equation (1.2DL + 1.6 LL) a factored loading of 340psf is calculated for the slab. The tributary area to be accessed in the design is 18”.

From examining the floor slabs throughout the building, it was assumed that all of its floor slabs are the same waffle design. A tape measure and ladder were used in order to obtain the measurements required for the analysis of the slab. The rebar used in the concrete is #3 rebar at 12” spacing. The width of the spacing between each stem is set at 2’-1”. The depth of each stem is 10.5” and the depth between the rebar and top of stem is 9”. The width of the stem was measured to be 5” and the top of the slab itself is 2.5” thick. The concrete strength was conservatively assumed to be 3000 psi, and the yield strength of the concrete was assumed to be 40,000 psi. All of the measurements and calculations used in the analysis of the floor slab can be found in Appendix B.

2.2 Roof Analysis

From inside the attic, it can be seen that the roof rafters are 2” by 12” Douglas-fir at 16” on center measuring 33’ in length. These wooden rafters are the primary roof support structure. The secondary roof support structure includes two rows of 12” by 16” I-beams supported by steel columns. The I-beams are connected directly to the wooden rafters and run the entire length of the roof. There are also 12” by 16” I-beams which run along the peak of the roof in each extension to the previously mentioned I-beams.

The next step in the roof analysis was to determine how much thermal resistance the roof was providing. From the outside the building it was clear that the roof has a slate shingle finish and from inside the attic, a base layer of plywood could be seen. Any all layers in between the plywood and the slate as well as the thickness of each layer were still needed. From reviewing *Air Conditioning Kaven Hall* by MacGregor, the roof composition was determined to be ½” slate shingles on top of ½” lumber sheathing on top of ¾” plywood. Beneath those layers are the 2” x 12” rafter made of Douglas-Fir. The roof also has outside and inside air films that protect against the weather. These materials along with their respected thermal resistance factors can be seen in Table 2.1. The R-Value is a shortened term for the thermal resistance rating. After viewing this chart, it is visible that the total R-Value for the existing roof is only 2.15, a particularly low value for the Northeastern United States.

Table 2.1 Existing Roof Composition and Thermal Resistance Factors

Component	R-Value
Outside Air Film	0.17
Slate, ½" Thick	0.05
Roof Boards ¾" Thick	0.94
Inside Air Film	0.62
Framing	0.37
TOTAL	**2.15**

The roof also includes four dormers which can be seen in Figure 2.3. Two dormers face the west, which is the side of the building that faces the rest of campus. There is another dormer facing north, and one more facing south. All of these dormers have the same dimensions. They are nine feet deep, eighteen feet wide and five feet tall (Brodeur, Elliot, Fox). A picture of the two dormers facing campus can also be seen in Figure 2.4.

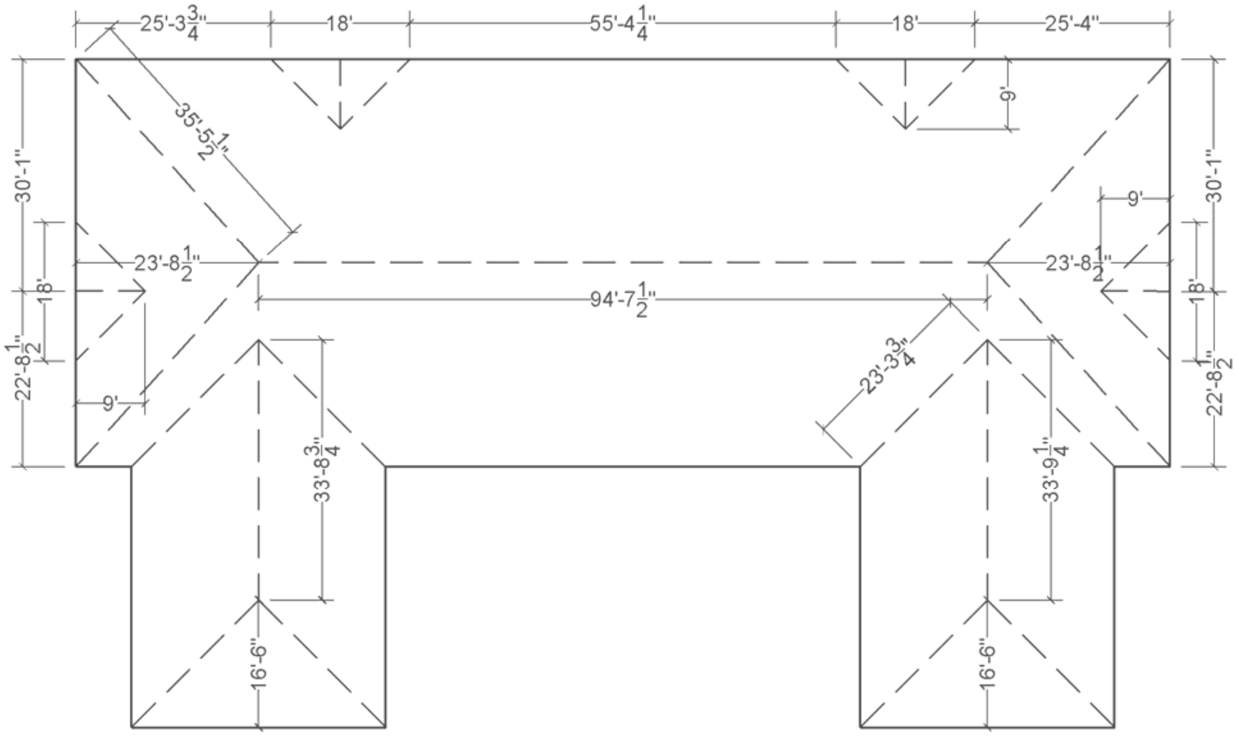


Figure 2.3 Existing Dormer and Roof Dimensions

Figure 2.4 West-Facing Dormers

Collar ties also run along the length of the attic roof and along the extensions. The collar ties are 2" by 8" Douglas-Fir and stand 11' from the floor along the length of the main roof and 7' along the extension roofs. The collar ties and rafters can be seen in the various cross section drawings in Figures 2.5 and 2.6. Part A of Figure 2.5 shows where the cross section was taken while part B illustrates the collar ties and steel columns. Part C illustrates the inner walls and the roof rafters. Figure 2.6 entails the steel columns and collar ties in part A while part B illustrates the area of the room.

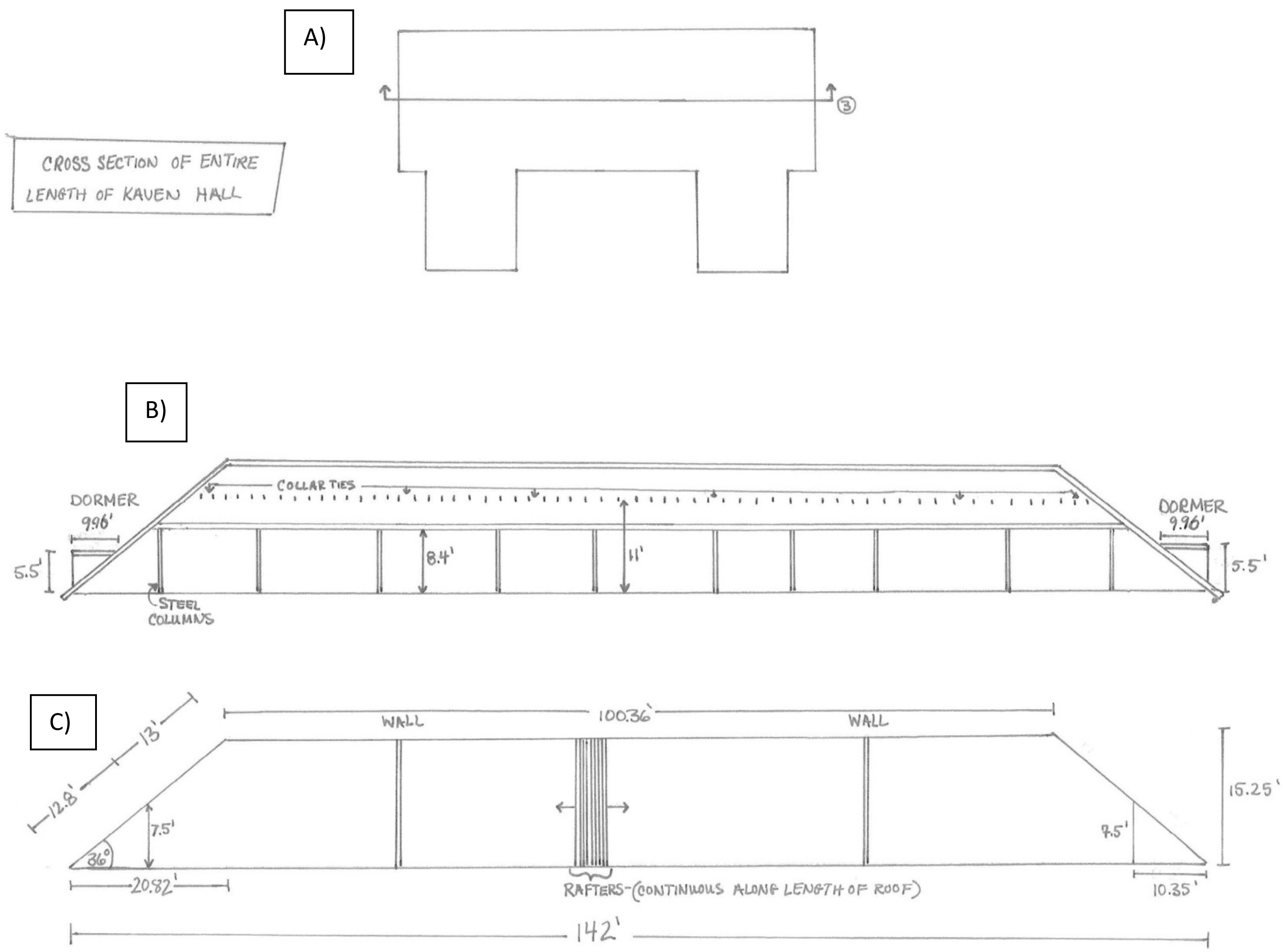


Figure 2.5 Cross Section of Length of Attic

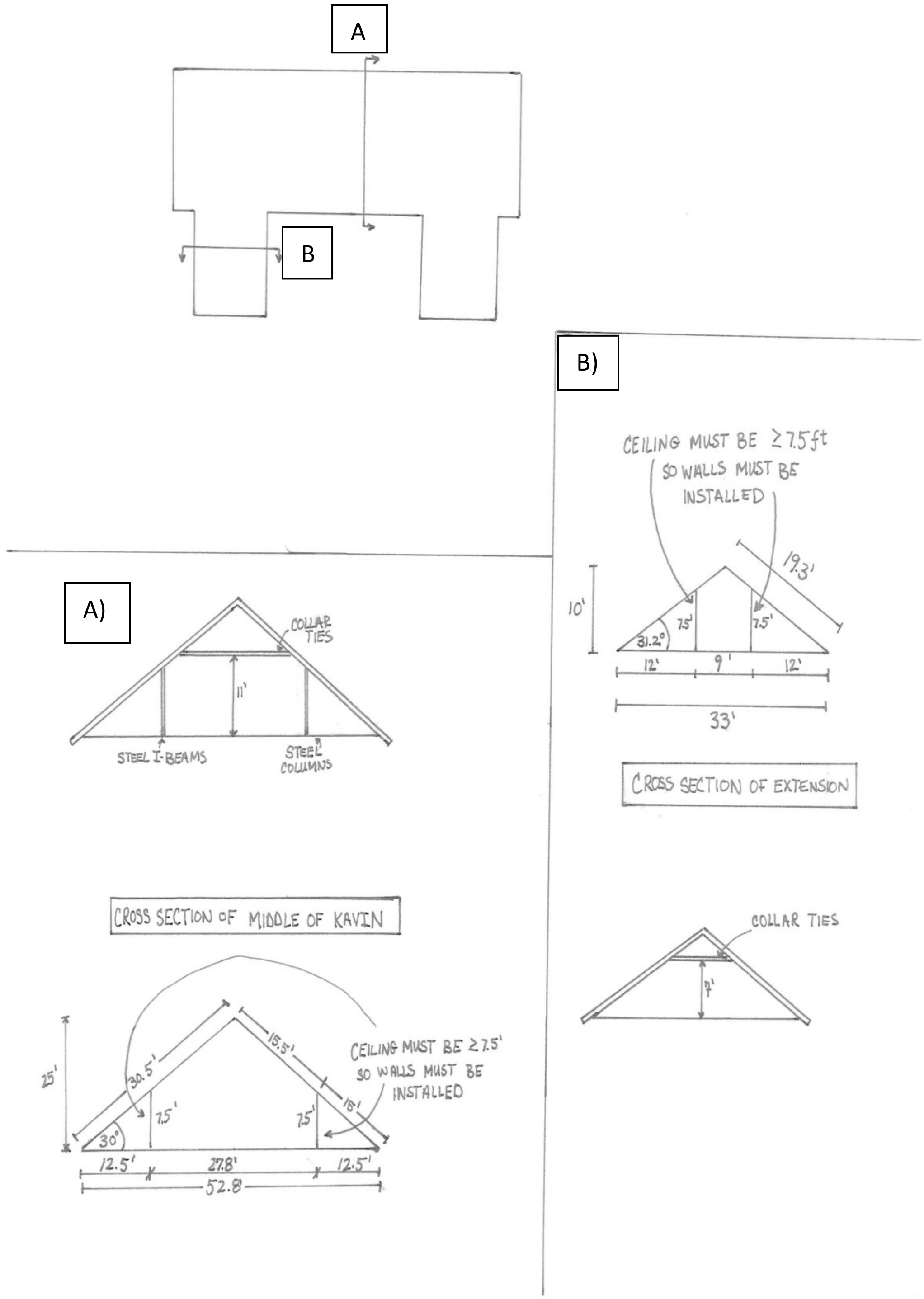


Figure 2.6 Cross Sections of Roof Peaks

In addition to the steel I-beams which support the roof, there are also two rows of vertical steel columns. The columns on the northern side of the building were found to be 4in diameter circular steel columns. The distance from the edge of the roof to the first column was measured with a tape measure, followed by the distance between each column. This same measurement process was repeated for the columns on the southern side of the building, which were found to be I-beams, not circular columns like the other row. All of the measurements were then used to draw the columns into the floor plan in AutoCAD.

Next the height of the peak of the roof needed to be determined at both the main peak and at the peaks of the extension roofs. Since it was difficult to get the height of the roof peak using a tape measure, the best idea seemed to be to get the distance from the floor to the top of the flat roof of the stairwell, which happened to be located directly below the ridge. Then, the distance from the top of the stairwell roof to the attic roof peak was measured. The height of the stairwell was measured to be 8’-3”, and the distance from the top of the stairwell roof to the attic roof peak was measured to be 7’. This meant that the height of the height of the attic roof peak was 15’-3”. This dimension can be seen in the cross section of Figures 2.5.

Determining the height of the roof peak in the extensions was a bit easier, as the roof was considerably shorter. It was found to be 10’ from the floor slab. After the heights of the two roof peaks were measured, the height of the collar ties was measured. The collar ties of the main roof were 11’ from the floor slab while those of the extension roofs were found to be 7’ from the floor slab. All these dimensions can be seen in the cross sections of Figure 2.6.

After all the structural aspects of the attic had been fully dimensioned, the dimensioned were double-checked to ensure that they added up correctly. The only measurements that did not add up correctly were the lengths of the rooms. These lengths did not add up to the total length of the building, but were instead off by less than two feet, a negligible difference. Next, the dimensions were compared to those found in previous MQPs. They were determined to be similar enough that margin of error was very small and most likely derived from the scale on the blueprints.

Once the heights of the roof peaks and the width of the rooms were known, algebra was used to determine the slopes and lengths of the roof. Cross section A of Figure 2.6 is the cross section taken at the middle of the main room. The height of the ridge was known to be fifteen feet-three inches and the width of the room was known to be 52’-10”. After careful trigonometry, the length of the roof was found to be 30.5'. The angle of incline was then found to be 30°. The same was done for cross section B of Figure 2.6, which shows a cross section of the extensions. Since both extensions have the same dimensions, their area and slope are the same. The length of the roof was calculated to be 19'-3". Trigonometry was then used to establish the angle of incline, which was found to be 31.2°.

2.3 Fixed Items

In the attic, it is apparent that there are two ventilation systems in the main room which occupy most of the floor space. One is used primarily for ventilation in the labs of the basement, while the other is used for the general exhaust of the building (Christopher Salter, Facilities). Photographs of these ventilation systems can be found in Figures 2.7, 2.8, and 2.9.

Figure 2.7 Primary Ventilation System

Figure 2.8 Secondary Ventilation System, Side View

Figure 2.9 Secondary Ventilation System, Front View

Next to the ventilation systems was what appeared to be a brick chimney. However, upon a closer look, it was determined this was not a chimney, but a brick ventilation pipe enclosure. The ventilation systems were attached to this "chimney" as a way to push the vented air outside. There were also parts of the ventilation system that went down through the floor in the chimney.

Located right next to the ventilation systems was a caged room. This room had walls composed of wood-stud framing and metal chain-link fencing, which could easily be removed. Inside this caged room were more items belonging to professors and old MQP projects from as far back as 1954 when the building was first opened. If cleaned out and dry-walled, this room could be used in the new floor plan. In fact, it is one of the only usable spaces in the main room. The location of the cage room, brick chimney, and both ventilation systems can be seen on the floor plan in Figure 2.10.

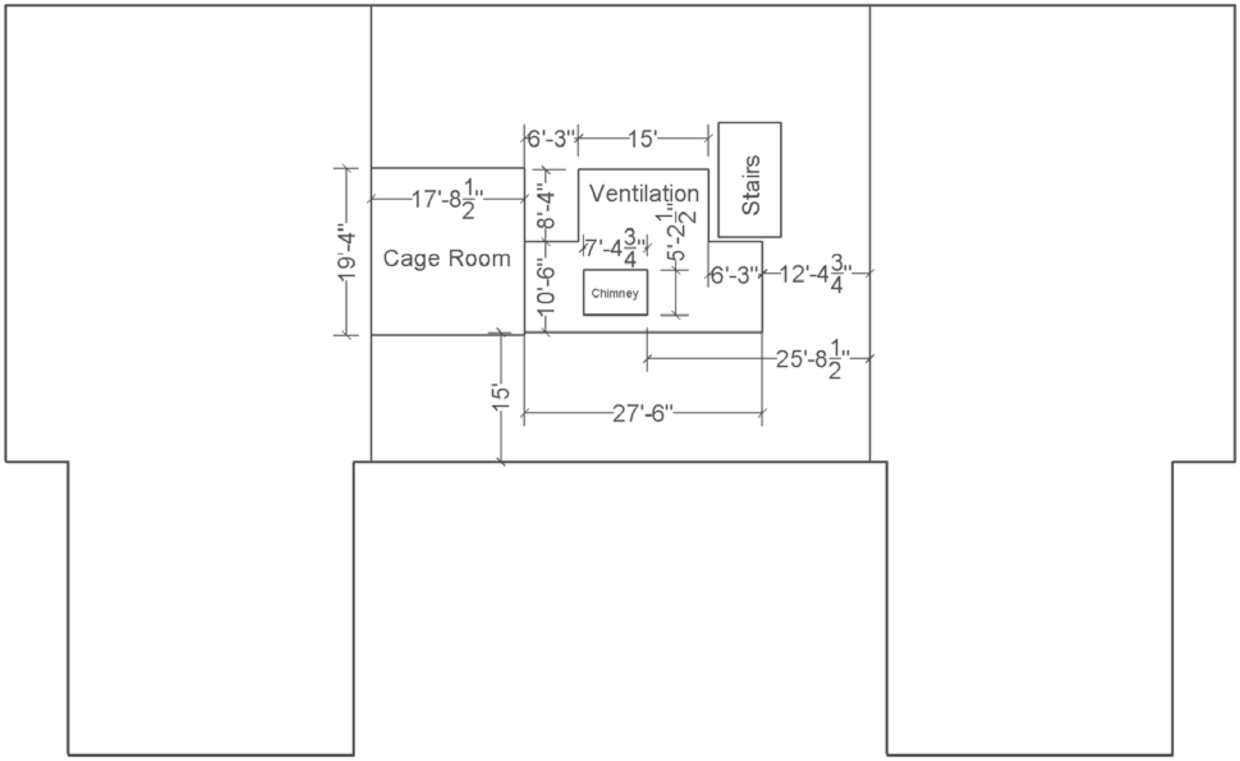


Figure 2.10 Location of Cage Room, Chimney, and Ventilation Systems

Other fixed items located in the attic included the structural steel columns discussed in Section 2.2. The location of each of these columns in relation to the perimeter of the building can be seen in Figure 2.11. These columns produced an obstacle for the purpose of this project, as they would need to be planned around. In order to convert the attic into usable space, these columns could not be allowed to obstruct any means of egress.

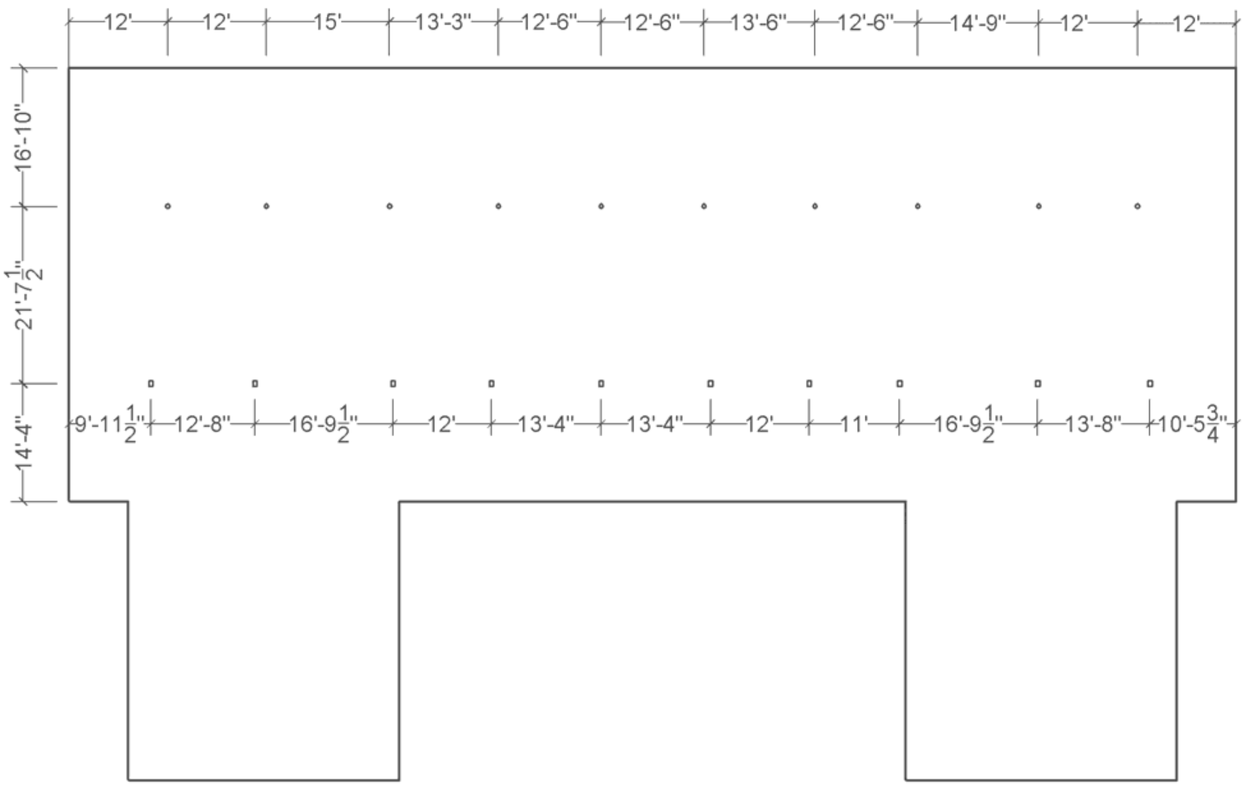


Figure 2.11 Location of Structural Steel Columns

Another obstacle found in the attic is a steel pipe running along the floor one foot above the floor located in between the cage room and the ventilation system. This pipe can be seen in Figure 2.12. The pipe is part of the sprinkler system, and would have to be moved in order to not impede egress. This can be done by one of two methods. The first; put in a whole new sprinkler system that could be hidden behind walls and the ceiling. The second; move this pipe elsewhere where it would not take away usable space or impede egress. A new system would be the most beneficial and reasonable since the renovated attic will need a fire protection system in order to comply with the *CMR*.

Figure 2.12 Problematic Sprinkler Pipe

2.4 Mechanical Systems

There were three major mechanical systems present in the attic of Kaven Hall. These three systems included a primary ventilation system, an exhaust ventilation system, and a fire sprinkler system. These three systems took up a considerable amount of space and were obstacles which would need to be planned around.

The primary ventilation system for the labs in Kaven Hall's basement was located in the attic. This ventilation system occupied nearly half of the usable space in the main section of the attic, which can be seen in Figure 2.10. While it takes up a lot of space, it is necessary for proper ventilation of the entire building and will need to be worked around.

A secondary ventilation system was also located in the attic and provided general exhaust ventilation for the entire building (Chris Salter, Facilities). This system is located behind the primary ventilation system and can be seen in Figures 2.8 and 2.9. According to Professor Roberto Pietroforte, this exhaust ventilation system could be moved to a more appropriate location in either the attic or the basement. Relocation or removal of this system could open up more usable workspace for the students and faculty of the civil engineering department.

The current sprinkler system in the attic of Kaven Hall is a dry pipe sprinkler system (Professor Fitzgerald, CEE Dept.). A dry-pipe system is composed of pipes that are filled with air under high pressure at all times while the water is held back by a control valve. If a sprinkler head were to be activated by a fire, it would open up causing a drop in the pressure inside the pipes. The control valve would then open and allow the water to flow throughout the system, activating every sprinkler head. This system was most likely chosen because there was no heat source in the attic. Had a wet-pipe system been used, the water in the pipes could have frozen during the cold New England winters, causing the pipes to burst.

The attic was cut basically in half by sprinkler system's pipes. When the sprinkler system was installed, the possibility of the attic being occupied was not taken into consideration. A six inch diameter pipe runs through the width of the center section of the attic, approximately one foot above the floor as seen in Figure 2.12. A second six inch diameter pipe runs parallel to the first just above head level, approximately seven feet from the floor. Numerous two inch diameter pipes run vertically between the two six inch pipes. This sprinkler pipe framework interferes with egress from the western half of the attic to the existing stairs.

In order to bring the attic up to code and gain proper access to the western half of the attic, the sprinkler pipes would need to be moved. While altering the layout of sprinkler systems is expensive, it is unavoidable if the attic is to be converted into workspace. In order to convert the attic into workspace, it will need to have additional sprinklers installed in order to meet fire codes included in the CMR. This means the current sprinkler system will need to be de-pressurized and removed, providing an opportune time to relocate the problematic pipes. Once this has been done a new system can be installed.

2.5 Available Space

Since the attic is enclosed by a slanting roof instead of vertical exterior walls, the usable area (in square feet) is not the same as the area formed by the perimeter of the building. According to the Massachusetts Code of Regulations; the amount of head space required needs to be no less than seven and a half feet (780 *CMR* 1208.2). In order to determine the actual amount of available floor space, a tape measure was used determine the location at which the rafters were 7'-6" from the concrete slab. The distance from this location on the floor to where the floor meets the roof was then measured. This was done along every wall. It was found that the location at which the rafters were 7'-6" from the floor was between 12' and 12'-6" from where the roof meets the floor for all sides of the building. The area of the attic which has 7'-6" of head room or more is outlined by the dashed line in Figure 2.13.

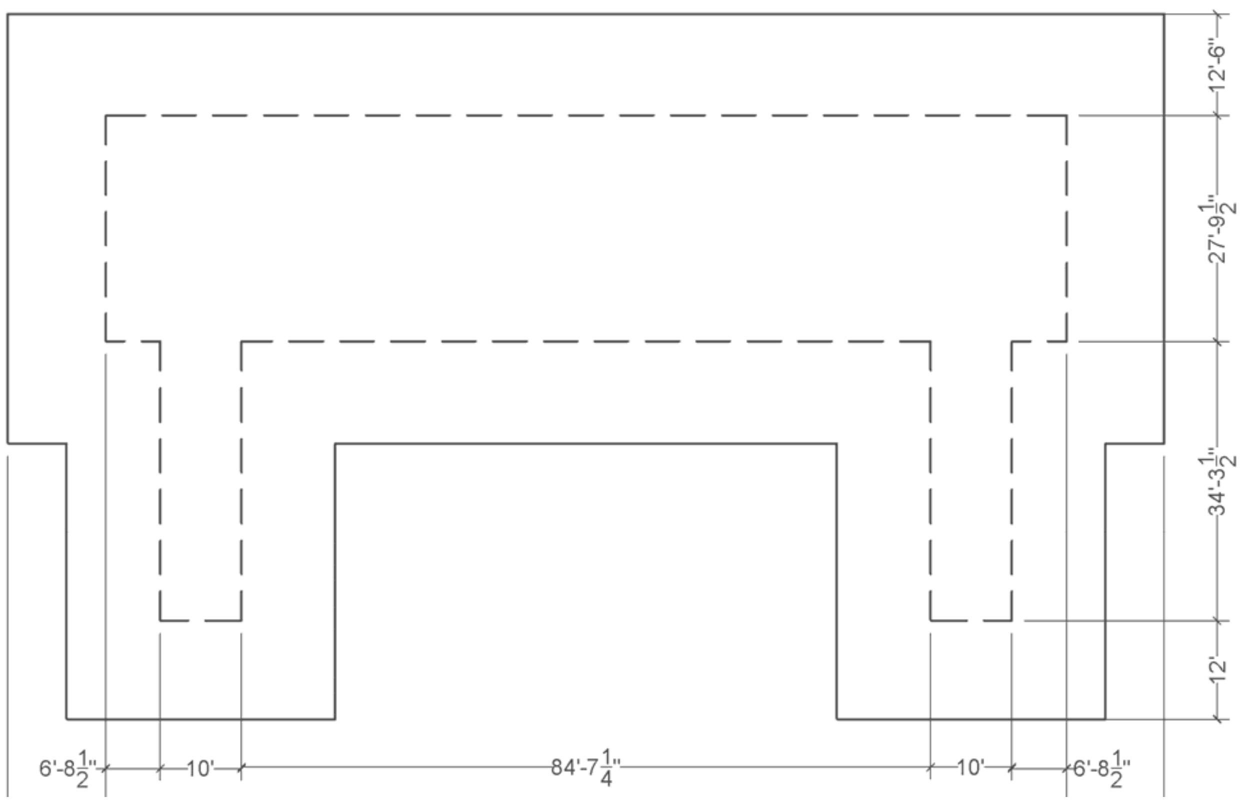


Figure 2.13 Area with 7'-6" of Head Room or Greater

From there, the structural and fixed items were superimposed on the drawing shown in Figure 2.13 to determine the actual usable square footage. This area was the area of the attic with

7’-6” of headroom or greater minus the fixed ventilation systems and stairwell. A floor plan drawing of the usable area can be seen in Figure 2.14. It turned out that the area available for use was 3,280 square feet.

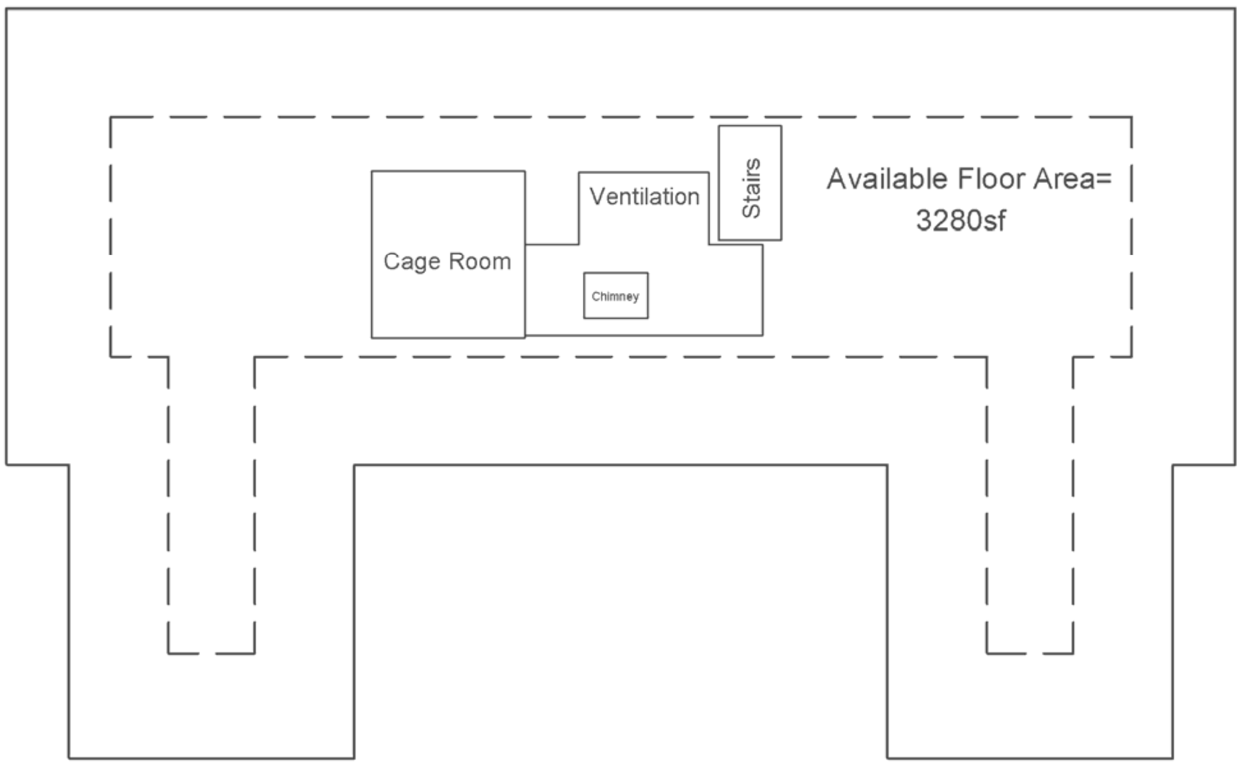


Figure 2.14 Usable Area

3 Code Compliance

Any renovations that are to take place in Kaven Hall must be compliant with the codes set forth by the Code of Massachusetts Regulations (CMR) and the Americans with Disabilities Act (ADA). The CMR and ADA will be referred to often throughout the course of this project. In the following sections, the relevant sections of both codes are discussed as well as how they pertain to this project.

3.1 Code of Massachusetts Regulations

According to the 780 *CMR* 3400.3, any renovations that are to take place to an existing building must comply with the *CMR* if the total cost of renovation is to exceed $100,000 or if the renovation would alter the structure by more than 30%. In this case the cost will exceed $100,000 and therefore, in order to pursue renovations on the Kaven Hall attic, all construction in the attic will need to comply with all the necessary requirements of the *CMR* and also the Americans with Disabilities Act (*ADA*). These necessary requirements include: the addition of drinking fountains, bathrooms, toilets, telephones, stairwells, accessible entrances, and accessible walkways. Not only does the code require the addition of the previously mentioned necessities, they also must be constructed by the specifications listed in the *CMR* and *ADA*.

Egress is one of the most important factors when designing, building or renovating a building. All hallways measured to be longer than twenty feet with an entrance at only one end are considered to be "dead ends." Rooms attached to these "dead end" hallways must be within twenty feet of an exit for emergency purposes (*ADA* 1016.3). The only types of rooms allowed to be constructed beyond that twenty foot point are closets and machine rooms. Currently, there is only one entrance to the attic, the stairwell in the center section. According to the 780 *CMR* 1018, the minimum number of exits shall be two. In order to comply with *CMR*, at least one additional exit will need to be constructed.

The 780 *CMR* 1003.2 requires that any area used as a general mean of egress shall have a ceiling height of no less than seven feet. Also stated in the *CMR* is that bathrooms need not have a ceiling height greater than seven feet. However, the minimum ceiling height of all occupiable spaces such as meeting rooms, offices, classrooms must be at least 7'6" (780 *CMR* 2108.2).

After calculating the usable space given the sloped ceiling, the height requirement, and the structural and fixed items, it was found that the attic has 3,280 ft^2 of usable space.

The current lighting in the attic is insufficient, as only a few fluorescent lights are installed throughout the entire attic. Sections 1, 2 and 3 of the attic are slightly illuminated while the extensions have only a single bulb between them. Every space intended for human occupancy shall be provided with natural light with means of exterior glazed openings in accordance 780 *CMR* 1205.2; or shall be provided with artificial light in accordance with 780 *CMR* 1205.2. The *CMR* requires a certain amount of natural lighting from the roof, and since there is currently no natural lighting at all, skylights and/or dormers must be installed in the roof.

The *CMR* provides strict provisions for illumination in bathrooms and hallways intended for egress. It reads that, all means of egress, including exit discharge, shall be illuminated at all times while the building is occupied. Also, this illumination level is not allowed to be less than one footcandle, or 11 LUX, the floor level, as stated by the 780 *CMR* 1006. Every bathroom and toilet room shall be provided with artificial light, and shall have an average illumination intensity of three footcandles, or 32.29 LUX, located 30 inches above the floor (780 *CMR* 1205.1). Artificial light shall be provided that is adequate to provide an average illumination of ten foot candles over the area of the room at a height of 30 inches.

There is currently no ventilation system installed for the attic. While there are two ventilation systems in the attic, neither is designed solely for the ventilation of the attic. In order to allow for the occupancy of the attic, a new ventilation system must be designed and provided. This can either be natural or mechanical, but one must be installed with the demands set forth by the 780 *CMR* 1203. If mechanical ventilation shall be used, then the net free ventilating area shall not be less than 1/150 of the area of the space vented (780 *CMR*1203.1). All bathrooms and water closets shall have mechanical ventilation as specified in780 *CMR* 1203.1. If natural ventilation is to be used, the "minimum openable area to the outdoors shall be 4% of the floor area being ventilated" (780 *CMR* 1203.4.1).

The Massachusetts State Building Code states that wind and snow loads show that the Worcester region requires any institutional roof to have a ground snow load of 55psf, and the building to withstand a wind load of 100mph (870 *CMR* Table 1604.10). The existing roof on

Kaven Hall was designed to withstand a minimum live load of 100psf (Brodeur, Elliot, Fox). Any changes in the design to the roof must be accounted for and able to withstand the existing loading conditions on the roof (780 *CMR* 1504).

The *CMR* also sets regulations for insulation installed in buildings and that insulation must meet the required R-Value. The R-Value is the measure of thermal resistance. The R-Value is very important because the roof must meet the standard R-Value set forth by the state of Massachusetts. This required R-Value can be seen in Table 3.1 below.

Table 3.1 Taken from CMR Table 1304.2.10

Roof Assemblies	Insulation Between Framing	Continuous Insulation
All-Wood Joist/Truss	R-25	R-19
Non-wood Joist/Truss	R-25	R-20
Concrete S Slab or Deck	NA	R-19

This table comes from the *CMR* Table 1304.2.10. Section 1304 of the CMR sets forth regulations for R-Values of roof top assemblies and these regulations are categorized by the county of Massachusetts in which the building is located. They are also separated by the materials that compose the roof, whether they are wood or metal. Since the roof in the attic of Kaven Hall was constructed entirely of wood with 2" x 12" wooden framing, the required R-Value is R-25 for insulation between framing. Currently, the roof has an R-Value of approximately 3.15. This value was determined using the information in Table 3.2 below (MacGregor, 1997).

Table 3.2 Components of Existing Roof

Component	R-Value
Outside Air Film	0.17
Slate, ½" Thick	0.05
Roof Boards ¾" Thick	0.94
Inside Air Film	0.62
Framing	0.37
TOTAL	**2.15**

3.2 Americans with Disabilities Act

In addition to complying with the *CMR*, any construction done to Kaven must also act in accordance with the American with Disabilities Act, or *ADA*. In order to meet *ADA* requirements for handicapped persons, construction must allow for all hallways and walkways to be accessible to all persons, and constructed with the dimensions discussed in the *ADA*. According to the *ADA*, all persons shall have access to all floors, so to allow for anyone handicapped to enter the attic, an elevator must also be installed in Kaven. This elevator is not just for the attic however, it must have access to all floors, from the basement up to the attic.

The renovation of the Kaven Hall attic requires that bringing the current space up to code and one of those codes dictates walkway dimensions. As stated by the *ADA*, all walkways must maintain a minimum clear width of 36" as to be classified as an accessible route (*ADA* 4.3.3). The same goes for any method of egress, which the *ADA* sets a standard of three feet for hallway width (*ADA* 4.2.4.1).

The *ADA* also sets forth requirements for forward reach. Since hallways constructed in the attic will allow for a forward approach only, a forward reach of 48" must be maintained while also maintaining a minimum low forward reach of fifteen inches (*ADA* 4.2.5). All halls, corridors, and other walking spaces shall comply with 4.3 of the *ADA* code. Accessible routes must also serve as a means of egress for emergencies in the case of rescue assistance.

Ground and floor surfaces along accessible routes and in accessible rooms including floors, walks, ramps, stairs, and curb ramps also have guidelines that need to be followed. These surfaces shall be stable, firm, slip-resistant, and comply with Section 4.5 of the *ADA*.

On every flight of stairs, all steps shall have uniform riser heights and uniform tread widths. Stated by the *ADA*, risers on stairs must be greater than 4" but cannot exceed 7". The tread, or depth, of the stairs must be greater than eleven inches, measured riser to riser. Open risers are not permitted. Also, stairs must also maintain consistent headroom of 80" up the slope. A related requirement listed by the *CMR* that determines stairwell dimensions is: landings of stair cases must be at least as wide as the stair case and must be as long as the width of the stairs, but can be greater (780 *CMR* 1009.4). The *CMR* also reads that: stairs must maintain a width of at least 44" (780 *CMR* 1009.1). Both the *ADA* and *CMR* agree that all stairways shall have handrails on both sides of the stairs.

The standard for the height of any handrail is that the rails must stand at least 34 inches above the walking surface, but no greater than 38" above the walking surface. The rail must be a minimum of 1½" from the wall, and the horizontal projection connecting the rail to the wall must be 1½" lower than the rail (*ADA* 505.5 and 505.6). See Figure 3.1 for visual representation.

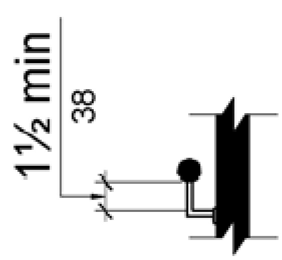


Figure 3.1 Requirement for Handrails Used for Stairs

There are also standard for the size of the rail used, depending on the cross sectional shape of the rail. If a circular rail is chosen, the cross sectional diameter cannot exceed two inches and must be greater than 1 ¼". If a non-circular rail is chosen, the perimeter must be at least four inches but no greater than 6 ¼". A non-circular rail also cannot have a cross section greater than 2 ¼" (*ADA* 505.7.2). The rail must extend one foot past the top step, going up the stairs, by code (*ADA* 505.10.2) as shown in Figure 3.2. Also, when going down the stairs, the rail must extend past the last step by a length equal to the tread depth (*ADA* 505.10.3) as shown in Figure 3.3.

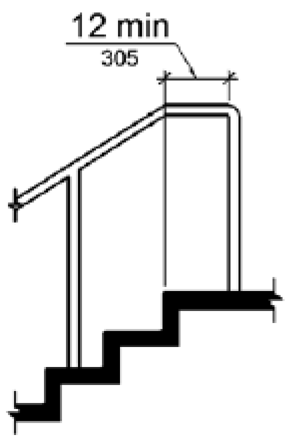


Figure 3.2 Requirement for Handrails at Top of Stairs

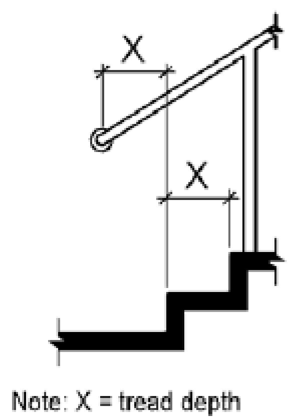


Figure 3.3 Requirement for Handrails at Bottom of Stairs

Accessible elevators shall be on an accessible route and shall comply with *ADA* 4.10 and with the ***ASME* A17.1-1990, Safety Code for Elevators and Escalators**. Elevator operation shall be automatic. Each car shall be equipped with a self-leveling feature that will automatically bring the car to floor landings within a tolerance of ½" under rated loading to zero loading conditions. This self-leveling feature shall be automatic and independent of the operating device (*ADA* 4.10.2).

Call buttons in elevator lobbies and halls shall be centered at 42" above the floor. Such call buttons shall have visual signals to indicate when each call is registered and when each call is answered, and all call buttons shall be a minimum of ¾" in the smallest dimension. The button designating the up direction shall be on top (*ADA* 4.10.3).

According to *ADA* 4.10, elevator doors shall open and close automatically. They shall be provided with a reopening device that will stop and reopen a car door and hoist way door automatically if the door becomes obstructed by an object or person. The device shall be capable of completing these operations without requiring contact for an obstruction passing through the opening at heights of five inches and 29" above finish floor. Door reopening devices shall remain effective for at least 20 seconds (*ADA* 4.10.6). Doorways shall have a minimum clear opening of 32" with the door open 90 degrees, measured between the face of the door and the opposite stop. Openings more than twenty four inches in depth shall comply with 4.2.1 and 4.3.3 of the *ADA* code.

Drinking fountains or water coolers, required to be accessible by *ADA* 4.1, shall comply with 4.15 of the *ADA* code. Spouts shall be no higher than 36", measured from the floor or ground surfaces to the spout outlet. The spouts of drinking fountains and water coolers shall be at the front of the unit and shall direct the water flow in a trajectory that is parallel or nearly parallel to the front of the unit. The spout shall provide a flow of water at least four inches high so as to allow the insertion of a cup or glass under the flow of water. On an accessible drinking fountain with a round or oval bowl, the spout must be positioned so the flow of water is within three inches of the front edge of the fountain (*ADA* 4.15.3).

Toilet stalls size must comply with the dimensions shown in Figure 3.4. Lavatories shall be mounted with the rim or counter surface no higher than 34" above the finish floor, and provide a clearance of at least 29” above the finish floor to the bottom of the apron. Knee and toe clearance shall also comply with *ADA* code. Hot water and drain pipes under lavatories shall be insulated or otherwise configured to protect against contact. There shall be no sharp or abrasive surfaces under lavatories. Bathrooms are also required to be accessible by 4.1 of the *ADA* and shall comply with 4.23 of the *ADA* and shall be on an accessible route.

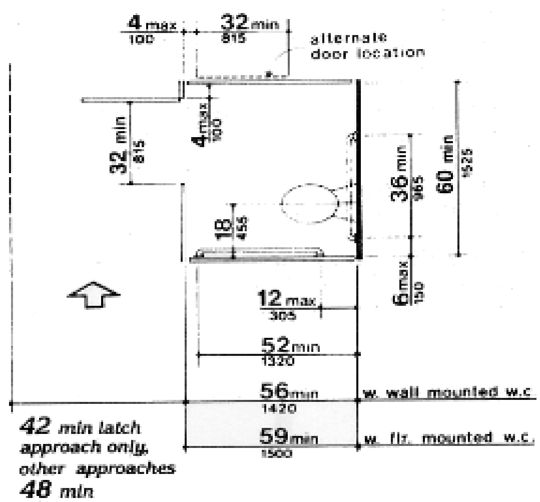


Figure 3.4 ADA Requirements for Bathrooms

Sinks shall be mounted with the counter or rim no higher than 34” above the finish floor, and a knee clearance that is at least 27” high, 30” wide, and nineteen inches deep shall be provided underneath sinks. Faucets shall comply with *ADA* 4.27.4. Lever-operated, push-type, touch-type, or electronically controlled mechanisms are acceptable designs. The diameter or width of the gripping surfaces of a handrail or grab bar shall be 1 ¼” to 1 ½”, or the shape shall provide an equivalent gripping surface. If handrails or grab bars are mounted adjacent to a wall, the space between the wall and the grab bar shall be 1 ½”. Handrails may be located in a recess if the recess is a maximum of three inches deep and extends at least eighteen inches above the top of the rail (*ADA* 4.26). Fixed storage facilities such as cabinets, shelves, closets, and drawers required to be accessible by **4.1** of the *ADA* code and shall comply with Section 4.25.

Alarm systems are required to be accessible, and visual signal appliances shall be provided in buildings and facilities in each of the following areas: restrooms and any other general usage areas, meeting rooms, hallways, lobbies, and any other area for common use (*ADA* 4.28). Public telephones are also required to be installed and accessible by the *ADA* 4.31.

4 Proposed Plan

In order to determine exactly what type of renovations would take place in the attic, many characteristics of the attic had to be taken into consideration. The first characteristic was the existing conditions. The attic had to be surveyed and evaluated to see exactly what was inside and how much space was available. From there, all the structural and fixed constraints that could not be removed were located and assessed. Next, the applicable *CMR* and *ADA* codes were reviewed to determine what space would be considered usable. After the code had been analyzed, the total usable floor area, in square feet, was calculated. After the usable space had been determined, two surveys were formulated. These surveys were created so that the students and faculty of the CEE Department could provide input as to what they thought the renovation should include. Finally the sizes of the rooms chosen to be built as part of the renovation were determined and a possible layout was formulated.

4.1 Determine Usable Area

Before any proposal for renovation could begin, the attic had to be surveyed. In order to survey the existing conditions, the original plans were located and extracted from the WPI Facilities building located on Hackfeld Rd. These plans, however, were not accurate, as they included only the outer walls of the building the existing stairwell. Omitted from these original plans were: the secondary roof structure, which includes steal I-beams and columns, and the ventilation systems. Upon a closer look, the dimensions were not accurate either, thus a new floor plan had to be created with the use of Auto-CAD. The new drawings included the interior walls, the stairwell, the ventilation system, the steel columns, and the chimney located in the middle room. However the new Cad drawing was not yet complete.

The permanent fixtures in the attic were some of the main concerns of renovation because they could not be moved. There are twenty steel columns, a load-bearing masonry stair shaft, two ventilation systems and a brick chimney that was used to bring vented air in and out of the building. The chimney, stair shaft and ventilation systems were all located in the middle room, eliminating most of the usable space in that room. The cage room was also located in the middle section, but was not considered fixed because it could be moved. The columns ran the length of the building and therefore, were an obstruction throughout the attic. Out of the 9,728.4sf of floor space in the attic, approximately 505sf were taken by the ventilation systems and the stair shaft. Table 4.1 shows the sizes of these permanent fixtures.

Table 4.1 Dimensions of Existing Fixed Items

Rooms	Area (SF)	Perimeter (LF)	Height (LF)
Chimney	38.5	25.2	Extends to Roof
Stair Shaft	92.2	40	8
Ventilation Systems	413.75	92.7	Extends to Roof
TOTAL	544.45	157.9	N/A

In addition to the loss of floor space due to these fixed items, there was even more floor space lost due to the slope of the roof. According to 780 *CMR* 2108.2, ceiling heights in all occupiable spaces must be no less than seven and a half feet. This meant that most of the floor space in the attic would be lost because the roof clearance was too low. In fact, roughly twelve and a half feet was lost around the perimeter of the attic due to the low ceiling height. After the usable floor area with at least seven and a half feet of head room was determined, it was then possible to find the amount of actual floor space that could be used for renovation. This area was the floor area with at least seven and a half feet of head room minus the fixed items in the attic. Out of the 9,728sf of floor space, only 3,280sf could be renovated and used as occupiable spaces. See Figure 4.1 to see the usable floor area.

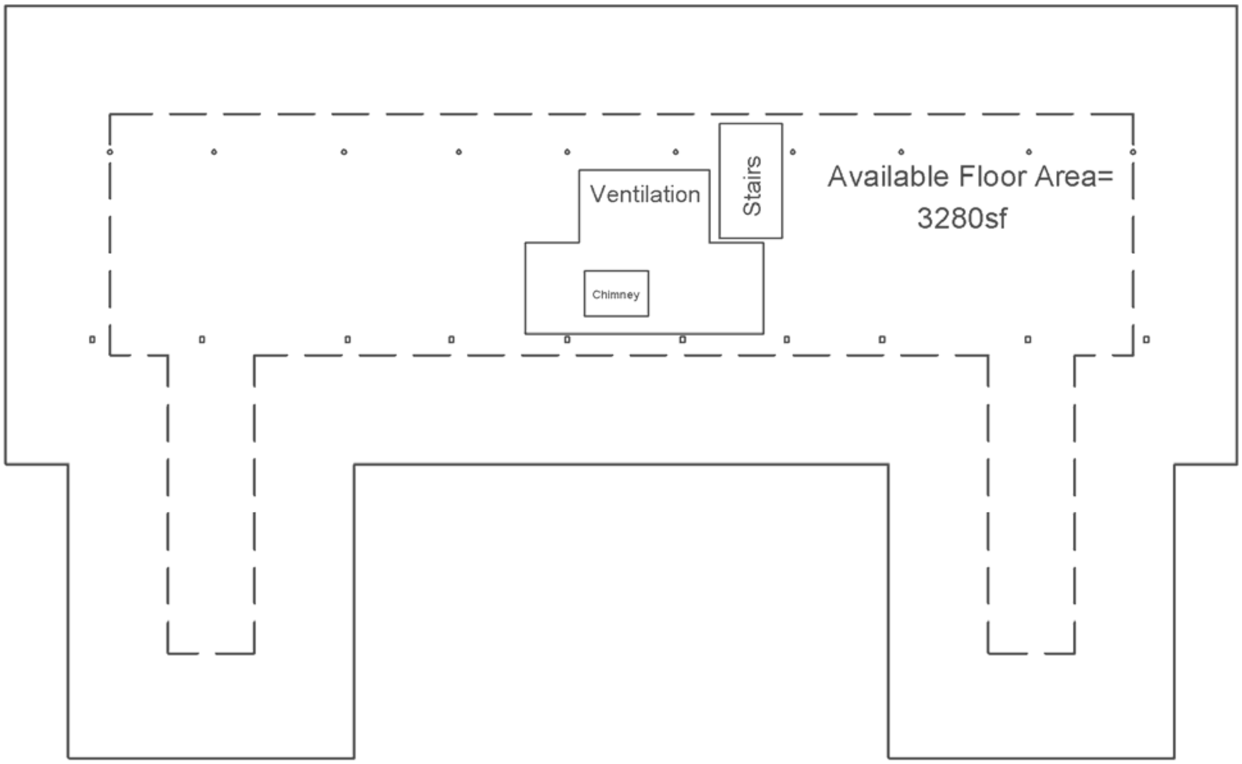


Figure 4.1 Usable Area in Attic

4.2 Student/Faculty Surveys

Once the amount of space that could be used for renovation was determined, what to do with that space was the next step of planning the renovation. The best way to decide what the attic should be used for was to ask the students and faculty themselves. From their answers, the most popular answers could be uncovered and the possibility of those ideas could be discussed. In order to ask all the students and faculty their opinions, two surveys were formulated and sent out to their respected audiences. Two surveys were created and not just one, because each survey was created to cater to the needs of the ones who would receive them.

The best way to sent out the survey to the students and faculty was then discussed. One idea was to print out numerous surveys and post them up around Kaven Hall in specific locations so that anyone passing by would see them. However this idea was quickly shot down because of the difficulty with collecting these surveys and the amount of paper wasted. The next idea was to send an e-mail out with the surveys attached and ask everyone in the department to open it up, fill in their answers, re-attach the survey and send it back. However this idea seemed too time-consuming for the faculty and students and the thought of many not answering due to the effort required made this option insufficient. The best way to send out the surveys seemed to be to e-mail them out, but to copy and paste the survey directly into the message. That way, the students and faculty could fill in their answers and simply reply to the message. The answers were then put into a folder labeled 'survey answers'.

Out of the two surveys created, one survey was sent to all the professors of the CEE Department while the other was sent to all the undergraduate students of the CEE Department. These surveys can be viewed in Appendix A. Even though all the undergraduate students and faculty were given the surveys, an accurate population was never established because the graduate students were left out. This happened because they were simply forgotten about when the surveys were e-mailed. Since e-mails were often sent to the students of the CEE Department, it was evident that students were grouped, by grade, into mailing lists. Freshmen, sophomores, juniors and seniors all had their own aliases. Professor Tahar El-Korchi assisted in providing these aliases; however the thought of the graduate student alias never came up, and therefore, they were never e-mailed.

On Monday October 6th, the students and faculty of the Civil and Environmental Engineering Department received the surveys via e-mail. Then, on Friday October 10th, the same population was resent the survey with a reminder to please respond if they had not yet done so. These surveys were set up in such a way that several ideas for what should be installed in the attic were listed and the surveyors were asked to rank them in order of most needed to least needed. There were five different ideas included in the students' survey and they were; tech suites similar to the ones found in WPI's Gordon Library, conference rooms, lounge space, individual study space and a classroom.

Out of a total 220 students who received the e-mail, only 43 replied. The answers from the surveys were then put into Microsoft Excel and tallied up. The answers were then averaged together to find the average rank on the scale of 1 to 5. Tech suites were the overwhelming winner with an average rank of 1.72, while receiving 26 out of 43 number one votes. A conference room was the next most popular room chosen, having an average rank of 2.95. Even though it only received three number one votes, it did receive the majority of the number two and three votes. A classroom was the third highest ranked option averaging 3.2 out of 5, followed by lounge space, 3.47, and finally individual study space, 3.63.

A classroom received the second most number one votes with nine; however this option also received numerous number four and five rankings, dropping its average rank. Conference rooms and lounge space both received three number one votes while the final two went to individual study space, which as a result, received the fewest number one votes. The options for conference rooms and additional lounge space were tied yet again, this time for the most number two votes with twelve, followed by seven by both tech suites and individual study space while a classroom received only five number two votes. The conference room option then led with seventeen number three votes while a classroom led the way with fifteen number four votes. The options for individual study space and additional lounge space then topped the results chart with fourteen number five votes each. The results from this survey can be seen in the Excel spreadsheet in Appendix A.

The faculty was given an almost identical survey as the students, with the only difference being two additional options. There was one additional option for faculty offices and another for teaching assistant offices. The faculty was given the same instructions as the students, but had to instead rank the options from 1 to 7, 1 being the most needed and 7 being the least needed. The results were not anything close to what was expected, nor were they like that of the student survey. Only three professors responded to the e-mail and the answers received were misleading. There seemed to be some misunderstanding with the instructions because instead of ranking the options, two of the professors ranked only the top three or four options, while one other member of the faculty had four different options ranked as a '2' and a question mark for another. Out of the three surveys returned, there were only two options labeled with a number '1' out of seven, one of them being the need for more individual study space while the other was the need for additional lounge space. The options were more graded than ranked, emitting the relevance of the survey. The results can be seen in Appendix A, although because of the confusion, they were not used in deciding what to do with the usable space in the attic.

After the surveys that had been filled out and returned were tallied up, the most needed types of rooms could finally emerge from the numerous options. It was then decided that since the tech suites option received the most number one votes and the highest overall rank, they would need to be installed above everything else. Tech suites are small meeting rooms where project groups can meet and do group work. These rooms usually contain a table capable of seating four to five people, a computer with many audio and video components and a large monitor that can make even the smallest prints viewable to all in the room. The main concern with the tech suites is the programs available on these computers. The term ‘tech suite’ comes from the suites in WPI’s Gordon Library. The computers in these rooms however do not have a sufficient amount of programs needed for Civil and Environmental Engineering. The programs needed for the CEE Department include: Auto-CAD, Primavera and Rivet, among many others.

Conference rooms received the second highest overall rank and deserved to be included in the renovation. With the size of the rooms being the main difference between conference rooms and tech suites, there are other differences. Typically in a conference room, there is also a blackboard or whiteboard where things can be written for everyone to see. Also, there is usually a projector and pull-down screen available to present projects, proposals and/or lectures. Currently there are only two conference rooms and both are hard to use. One of the conference rooms in Kaven Hall is on the second floor in a room off of Room 207A. It is usually locked however and has been turned into more of a small computer room with computers lined across two walls and a printer that take up much of the room. It seems that this conference room also doubles as a rest area as students are frequently caught taking naps in this room, making it unavailable for students to use it that need to. The only other conference room in Kaven is on the first floor. This room is not usually locked but it is in use the majority of the time. There are only certain hours of the day which this room can be used, as it is pre-scheduled for meetings very often. The need for an additional, more convenient conference room is then seen, and doubled, when the conditions of the other two rooms are considered.

An additional classroom was the option that received the second most number one votes. Kaven Hall only has five classrooms currently, and only one of these classrooms could be considered a lecture hall. Two of these classrooms have been converted into computer rooms over the years and are therefore used accordingly. Out of the two remaining classrooms, one is used only for graduate classes and the other can only seat approximately eighteen students. When this information is considered, a classroom seems like a great idea to include in renovation. However, there are many open classrooms throughout WPI’s campus and due to the recommendation of the advisor of this project, Professor Pietroforte, a classroom will not be utilized in the renovation process.

Additional lounge space was the item that received twelve number two ranks and seventeen number three ranks, the most in both categories, out of five. There is an existing lounge in Kaven; however there is not much to it. Currently there are three tables with chairs, and two walls covered with mailboxes for students in this lounge. Another lounge in the attic could provide students with a place to relax in between classes, without having to sit on the floor in the current lounge because there are not enough tables or chairs. If a large enough lounge were to be created in the attic, there would also be the possibility of converting the current lounge into more offices which are always in need, as some members of the faculty are forced to share cramped rooms. A new lounge would include comfortable chairs, couches, a television and coffee-style tables instead of the current chairs and tables in the first floor lounge.

The last option in the survey was the addition of individual study space. This option received the lowest count of number one votes, averaged the lowest rank in terms of necessity and received the most number 5 votes, when number five was considered to be the least needed. All this in mind, individual study space is still a priority. For one, quiet study space is always needed, and with Gordon Library containing all the cubicles on campus, it can often be hard to find one to use. It can be especially hard around finals time, so a space in Kaven to study alone quietly would benefit every student who is in the CEE Department. Another characteristic of the individual study space is that it does not take up much room. It does not require a specific dimension or require the installation of any equipment. Cubicles could be distributed down a narrow hallway if needed. The point is they require very little room and even less maintenance, and they will always be useful.

The survey helped decide what types of rooms to include in the renovation but that does not mean they can be added. Sometimes certain types of rooms are just not feasible in terms of money, equipment, time and/or space. Any renovation must also adhere to the *CMR* and *ADA* codes, which place even more constraints on any work done. A classroom for instance, is just not feasible in the attic because of the space needed for a classroom. There is a minimum amount of usable space in the attic and in order to install a classroom, two or even three of the other proposed rooms for installation would no longer be considered in the renovation. Cubicles for individual study space, on the other hand, can be placed anywhere they will fit, and whether there are twenty cubicles installed or just two, there is still some space for quiet study.

4.3 Required Renovation

While it is clear what types of rooms the students thought should be added to the renovation, code compliance must also be considered. According to the *CMR* and *ADA* codes, the renovation of Kaven Hall's attic must include the following: one bathroom for each gender, a drinking fountain, at least one additional access way to the attic and an elevator. Also, the attic must be made accessible to all persons regardless of physical handicaps. This means that not only does the code require the installation of these rooms, but hallways must be developed according to the code, a minimum head clearance of seven and a half feet must be maintained and certain standards for illumination and ventilation must also be adhered to.

Before deciding what types of rooms the renovation should include, the usable space must be determined. This is not just the usable space that is left after the subtraction of the areas lost to the existing fixed items, but also the space left after the addition of the bathrooms, stairwells and an elevator shaft.

According to the Massachusetts State Building Code of the *CMR*, all floors must have an accessible restroom facility that can be used by all persons. This means that not only must bathrooms be installed, but they need to be compliant with the code which designates sizes and heights of sinks, hand rails and toilets. The ADA has many requirements set forth about bathrooms including: Water Closets found in section 4.16, Toilet Stalls found in 4.17, Toilet Rooms in 4.22, Bathrooms in 4.23 and finally Handrails and Grab Bars found in section 4.26. The particular placement of these bathrooms was also of great importance due to the existing location of waste drains used by the second floor bathrooms.

Since bathrooms did have to be installed, the best possible location for these bathrooms seemed to be directly above the existing bathrooms on the second floor. This way, the piping could be extended one more story to reach the attic without too much construction. However this location in the attic provided ceiling heights that were too low and unacceptable according to the 780 *CMR*, Chapter 10. The bathrooms thus had to be moved, ever so slightly, to maintain enough head room. They were placed just close enough to the original planned location so that the head clearance was at least seven feet, and was still close enough to the waste drains. The dimensions were then calculated by measuring and averaging the typical bathroom in WPI and in various stores. The dimensions of the bathrooms were found to be six feet by seven feet. See Figure 4.2 on the next page to see the plan view location of the bathrooms.

Existing access to the attic in Kaven Hall is extremely substandard. Not only does the attic contain only one stairwell, that one stairwell does not even meet the guidelines for stairs set forth in the Chapter 5 of the *ADA* and Chapter 10 of the *CMR*. According to the *ADA*, there needs to be at least two means of egress, which means two sets of stairs. With the very limited space in the attic, the placement of the stairs was vital to the renovation of the building. Taking a recommendation given by Cory Brodeur, Paul Elliot and Tim Fox, the authors of *The Renovation of the Kaven Hall Attic*, the best scenario for adding stairs was to extend the current stairs, which travel from the basement to the second floor, up to the attic. The *ADA* sets guidelines for the slope of stair cases as well as the width and the landing of all stairwells. This made any other location extremely difficult to design for, so this location was decided to be the best.

A cut would then need to be made in the concrete floor slab of the attic in order to extend both sets of stairs. This scenario provides the most efficient use of space in the attic while also requiring no termination of space on other floors. The placement of these stairs can be seen on the floor plan in Figure 4.2. The stairs will be designed according to both codes. The dormers above these stairs provided sufficient head clearance the length of the stairs, but reconstructing these dormers would provide Kaven Hall with more natural lighting and ventilation. With the extension of the stairs to the attic, access was improved, but still not acceptable.

In order to make egress to and from the attic acceptable, all handicapped persons had to be able to gain entrance into the attic. This required that an elevator be installed. An elevator is very beneficial for general access to the various floors of the building for all persons and for bringing large, heavy samples from the basement floor to any floor needed. The big question with the elevator was where to install it. Taking another recommendation given by Brodeur, Elliot and Fox, the best possible location for the elevator shaft would be the current stair shaft, which was the only accessible entrance to the attic. The main concern with this location was that these stairs did not go all the way down to the basement level; in fact they only traveled to the second floor. This means that the shaft would need to be descended to the basement level and because of this, a cut would need to be made in the concrete slab on both the first and second floors.

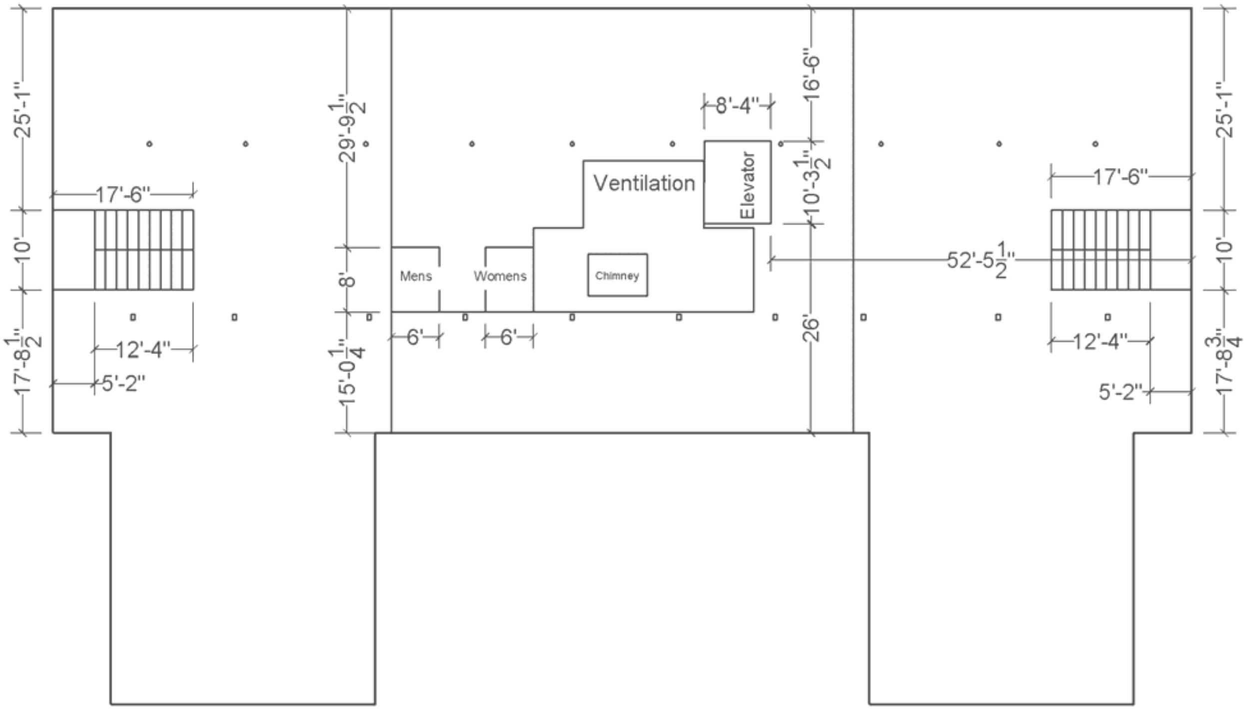


Figure 4.2 Locations of Required Additions

This location was considered very carefully as to not terminate too much of the various spaces on the various floors. With the shaft being placed in the current stair shaft, there would be some loss of space on every floor. In the basement, a portion of the concrete laboratory would be lost, but it would not be a large area. In order to place the shaft in this location, a nine foot section of the counter and cabinets would be removed and a machine would need to be relocated. Also, the addition of a machine room is mandatory on the basement level. It will be placed directly connected to the shaft and would only require the removal of more countertop and cabinets.

On the first floor, approximately half of the faculty coffee/copy room would be lost. There would still be plenty of room, however, to house the copy machine, sink and cabinets currently in that room. The second floor would also require some change but the least amount of any floor. A section of Room 206, Tahar El-Korchi's old office, would lose six inches of space for approximately thirteen feet of wall. This area only adds up to six and a half square feet lost. In the attic, the area of the shaft would be slightly changed. It would be built one foot wider than before, but would be three feet shorter, in terms of length not height, as well. See Figure 4.2 to see plan view location of elevator shaft next to the ventilation systems in the attic. The shaft will be designed to maintain its own weight and the weight of the elevator cab.

Table 4.2 Dimensions of Required Additions

Fixed Items	Area (SF)	Perimeter (LF)	Height (LF)
Elevator	86	37.3	8
Stairs (2)	350	60	N/A
Ventilation System	413.75	92.7	Extends to Roof
TOTAL	1007.65	190	N/A

Another renovation that must be completed has to do with the sprinkler system. The sprinkler system is very old and outdated. It also includes a six inch diameter pipe that runs across the width of the middle room in the attic about one foot from the floor. An additional six inch sprinkler pipe runs across both the extensions in the attic. These pipes cannot stay in their current locations because it would impede egress. It is very dangerous to have pipes there and would therefore need to be relocated. A new sprinkler system would be installed. A dry-pipe system would be installed, which is the same type of system currently in the attic, but a more up to date system would be the one installed. The proposed sprinkler pipes were to be hidden behind the wall and ceiling, however the sprinkler heads would not.

4.4 Heat Loss

Part of this renovation will need to include updating the insulation in order to meet the requirements set forth by the CMR in Chapter 13. In order to determine the type and amount of insulation needed for this particular roof, the thermal resistance of the materials must first be calculated. Then the amount of thermal resistance needed must be determined so the existing R-Value can be subtracted from the required R-Value to find what is needed for compliance. The thermal resistance, or R-Value, of a material is a rating given to the material in terms of how much heat is lost through conduction of that material. The larger the R-Value is, the greater the thermal resistance. R-Values are important because they can be summed to find the total thermal resistance of a system constructed of varying materials. The overall coefficient of heat transmission, U, may then be calculated by taking the inverse of the R-Value. The value of U is then used to calculate heat loss (MacGregor, 1997).

According to Table 1304.2.10 from the CMR, the required R-Value for a roof top assembly constructed of wood is R-25. The existing roof has an R-Value of only 2.15, considerably less than what is required. If the required thermal resistance needs to be R-25 and the current thermal resistance is rated only R-2.15, this means that insulation must be added and that insulation must have a total R-Value of 22.85. After researching insulation and the different types and the R-Values that accompany those types, foam insulation was deemed to be the best choice. According to the ESP Energy Company, foam insulation can supply R-Values ranging from R-4 to R-8 per inch. If an R-Value of 22.85 must be accomplished, either six inches of R-4 insulation, five inches of R-5 insulation, four inches of R-6 insulation or three inches of type R-8 insulation must be installed to comply. The R-8 insulation was chosen for this project. In addition to adding insulation to the roof, vapor seal and gypsum board will also need to be installed. The materials and thermal resistance values for the proposed roof can be seen in Table 4.3.

Table 4.3 Proposed Roof Materials and R-Values

New Roof Composition	R-Value
Outside Air Film	0.17
1/2" Slate Shingles	0.05
3/4" Plywood	0.94
Vapor Seal	0.1
3" Insulation (R-8/in)	24
Inside Air Film	0.62
Framing	0.37
1/2" Gypsum Board	0.5
TOTAL	**26.75**

After the roof had been brought up to code according to the CMR, in terms of energy conservation, the amount of heat loss could then be determined. Heat is a form of energy and thus the units of heat and heat loss must be units of energy. The units used for these types of calculations are called British Thermal Units, or BTUs. A BTU is defined as the amount of heat energy required to raise one pound of water one degree Fahrenheit (MacGregor, 1997). The amount of BTUs lost is often categorized in amount per hour, BTU/h. From research of the first MQP; *Renovation of the Kaven Hall Attic* by Brodeur, Elliot and Fox, and additional research, it was determined that the amount of heat lost in the existing roof was roughly 260,000BTU/h. From there, calculations were done to determine the amount of heat loss for the new roof. The calculations and a chart used to determine this heat loss of the new roof can be seen in Appendix C. From these calculations, it was determined that the HVAC system to be installed in the attic must produce 21,723BTU/h to remain code compliant. According to the *CMR*, the HVAC system that can provide at least 21,723BTU/h can supply 65,000BTU/h (*CMR* 1305.3.3(1)).

4.5 Possible Layout

Much deliberation was done in order to uncover exactly which rooms to install and include in the renovation. The survey answers were weighed heavily but also the feasibility of these rooms and the space in which they would be placed were considered. After the required installation of two additional stair cases, an elevator and two bathrooms, possible layouts could finally be planned. With the addition of these items, the usable floor area became 3,366sf. With the usable area finally calculated and the fixed items in place, the rooms to be included in the renovation could be chosen, their areas calculated and their position on the floor plan, decided.

The size of all the rooms from the surveys had to be considered before the rooms chosen to be included in the renovation could be picked out and placed into the floor plan. Then, with the dimensions and areas of all the rooms from the survey, the best options for installation could be considered. Table 4.4 below shows the average room sizes, taken from WPI's offices, tech suites, lounges, conference rooms and classrooms.

Table 4.4 Proposed Rooms

Rooms	Typical Areas (SF)	Typical Perimeters (LF)
Classroom	800	170
Conference Room	325	76
Lounge Space	300	80
Faculty/T.A. Office	80	35
Tech Suite	150	50
TOTAL	1655	

Since there was such limited space in the attic, a classroom was decided against. It would take up far too much room and take away from the addition of other rooms. It was decided that tech suites would definitely be part of the renovation, as well as at least one T.A. office, some individual study space, a conference room and additional lounge space.

The location of these items was the next thing discussed. In order to determine the locations of the various rooms, Auto-CAD was used to draw in the rooms wherever they would fit. Many of the rooms were placed in various locations to figure out which room belonged where. These new rooms had to be placed around the existing constraints, the elevator, the two stair cases, the ventilation system and the bathrooms. The tech suites were the first rooms to be given a permanent location in the attic. They were placed first because of the importance of their addition. They were the number one necessity, as determined by the CEE Department, and therefore were treated as so. They were placed in the third section of the attic along the inner existing wall and next to the new stair case.

The small areas available for use in the extensions off sections one and two were then designated as faculty and/or teaching assistant offices. From there, the lounge space was determined and placed right outside of the bathrooms. Individual study space was then placed in the space between the elevator shaft and the existing wall between section three and the middle room. Finally, the space in section one had to be filled. A classroom was still under discussion even with the dismay of Professor Pietroforte. It was finally concluded that a large conference room was benefit the department the most, and was therefore installed. The finalized floor plan can be seen in Figure 4.3.

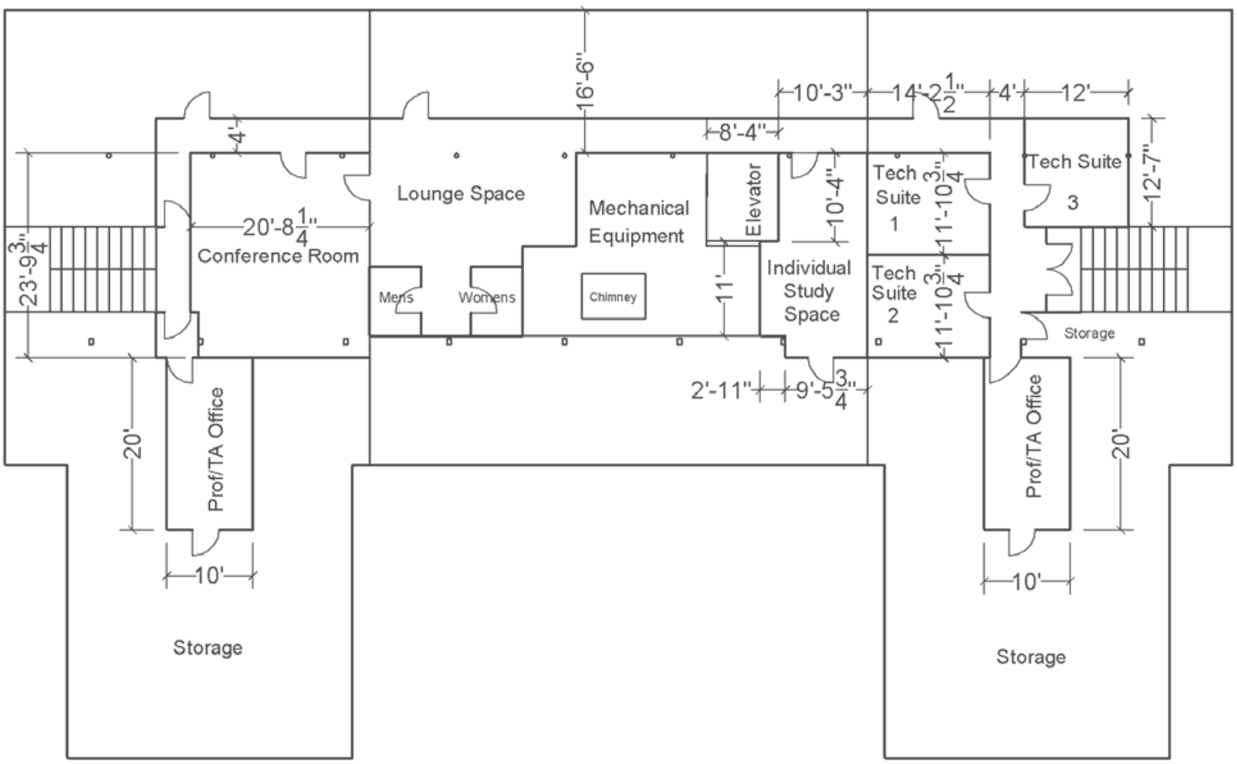


Figure 4.3 Proposed Floor plan

5 Structural Design and Analysis

There are two main elements for the final design of the Kaven Hall attic, which include a floor plan layout and structural alterations required by the ADA and CMR codes discussed earlier in the report. These components were designed in order to satisfy the needs and desires of the faculty and students currently attending WPI, in which their aspirations for the current space in the Kaven Hall attic were described in the surveys in Chapter 3. The existing fixed structures were the first thing that needed to be re-designed including the stairs and current roof structure. In order to comply with the ADA and CMR codes, structural alterations and additions were required to be designed in order to satisfy these requirements, and those alterations included the design of an elevator, skylights, and dormers for the current attic.

5.1 Ceiling Heights

The minimum ceiling height requirement compliant with 780 CMR 503 requires the height of the ceiling to be 7'-6". The ceiling throughout the attic is a sloped ceiling, which takes away most of the available space. Since the ceiling is sloped the best idea for natural lighting will be the installation of skylights in order to satisfy the natural light requirements described in the CMR code. Each of the interior walls designed will be partitioned walls, and will only meet the roof on the borders of the attic space. The height of the bathrooms will be 8' and will include a suspended roof. In order to acquire a proper representation of the ceilings heights look at ceiling cross-sections shown in figure 1.6 and figure 1.7.

5.2 Re-design of Roof

Before renovation could take place, the subject of illumination and ventilation had to be discussed. Chapter 12 of the *CMR* discusses provisions for illumination of an occupied building. Chapter 12 discusses the necessary illumination required in usable rooms, excluding bathrooms and hallways. Chapter 10 of the *CMR* discusses the illumination for hallways and bathrooms. While Chapter 12 concentrates on illumination, it also touches upon ventilation. Occupiable spaces must be ventilated and meet the demands set forth by the 780 *CMR*, Chapter 12. One option to provide the attic with lighting is to install recessed lighting throughout the entire roof. However, this option is very costly in terms of both installation and electricity. A better idea would be to install dormers and skylights at various locations. Skylights and dormers would solve the problems of ventilation and illumination. The design and installation of these skylights and dormers is costly, but they would provide natural lighting to the attic for as long as the building is occupied and would help bring the attic into compliance with codes.

There are two existing dormers above the two proposed locations of the new stairs. These dormers do provide enough height clearance above the stairs, however a little reconstruction to these dormers would provide the attic with much more natural lighting and natural ventilation. The existing dormers are considered to be gable-style and are eighteen feet wide and only five feet tall. A typical gable dormer can be seen in Figure 5.2; however the gable dormers on top of Kaven are a little different than the normal gable style dormers. The dormers on top of Kaven Hall are considered to be gable dormers without sidewalls, and can be seen in Figure 5.3 and Figure 5.4. Figure 5.3 is a structural drawing of a typical gable dormer while Figure 5.4 is a photograph of an actual dormer atop Kaven Hall. These dormers can be reconstructed so that they keep the same footing width of eighteen feet, but have a much taller height, which would allow for the installation of a window in each dormer. They could also retain their form as gable dormers.

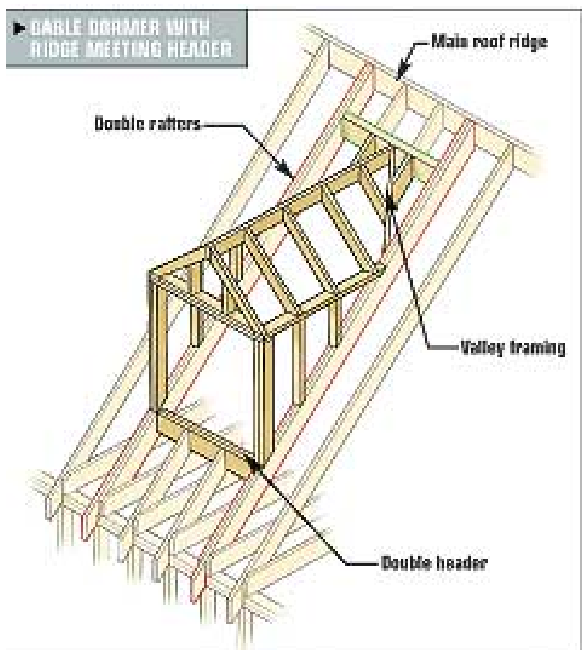


Figure 5.1 Typical Gable Style Dormer

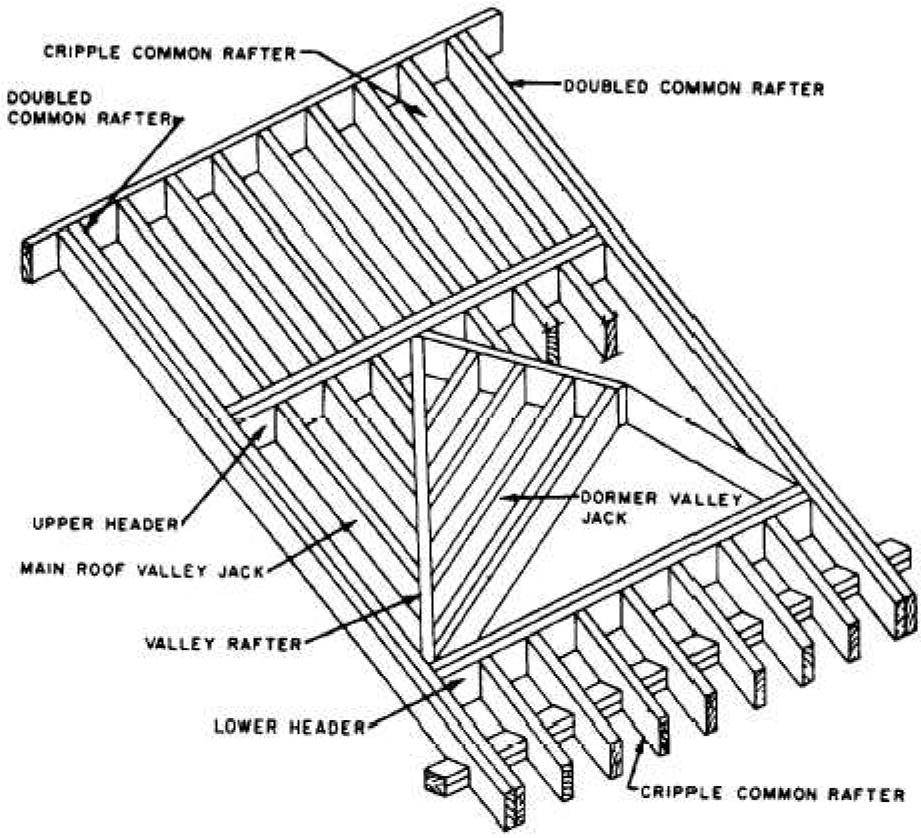


Figure 5.2 Structural Layout of a Typical Dormer without Sidewalls

There are also two more dormers in the roof structure that face the rest of campus. These dormers do little for the building, providing only a small amount of natural ventilation to the attic while also being aesthetically pleasing. Much thought went into exactly what to do with these dormers. The idea that they should be taken out entirely was discussed in detail. If they were taken out, two additional dormers could have been installed. These dormers would have been in slightly different locations as to provide the maximum amount of lighting to the attic. These new dormers would have been shed style dormers (flat-roofed dormers), ran eighteen feet wide just like the current dormers, and provide much more than the required amount of natural lighting to the attic. This option, however, was not feasible nor was it necessary.

The next idea was to again take out these two dormers, but to install one large dormer that ran the width of the main room. This idea was never taken too seriously. A dormer that big could structurally alter the roof and that is beyond the scope of this work. Finally, the conclusive plan for the roof structure was determined. Instead of deleting the two dormers that face campus, these dormers were altered. They were altered just like the two dormers above the new stairs, so they would maintain the original width, but have a greater height of ten feet instead of five. A window was then placed inside these dormers to provide natural lighting to sections 1 and 3. As an add-on to this plan, another dormer would be placed in between these two. This dormer was constructed and designed with the same dimensions as all other dormers on the roof. It was eighteen feet wide and ten feet tall. However, these three dormers facing campus would not provide any additional floor space. They would exist strictly for the purpose of bringing natural ventilation and illumination into the attic. The new roof layout with the five dormers can be seen in Figure 5.3.

Although these dormers will provide a sufficient amount of illumination in the attic, not every space in the attic could be lit up by them. That is where the installation of skylights came into the project. Skylights, installed at various locations in the roof, would provide rooms that are not illuminated by the dormers with natural light. They were planned to be installed at key locations in the attic to provide enclosed rooms with lighting. They were installed above the individual study area, in two of the three tech suites and above the conference room. The location of all new dormers and skylights can be seen in Figure 5.3. Figure 5.4 then shows the location of the skylights and dormers superimposed onto the floor layout of the attic.

This new layout will provide the faculty and students of the CEE Department with an updated and fully equipped addition. Although it is not an addition to the building, it is an addition to the useable space in Kaven Hall. With the installation of bathrooms, two additional stair cases and an elevator, the attic would finally be code complaint as well. The dormers and skylights will also have a large impact on the attic. The added illumination and windows brought in much needed views and ventilation.

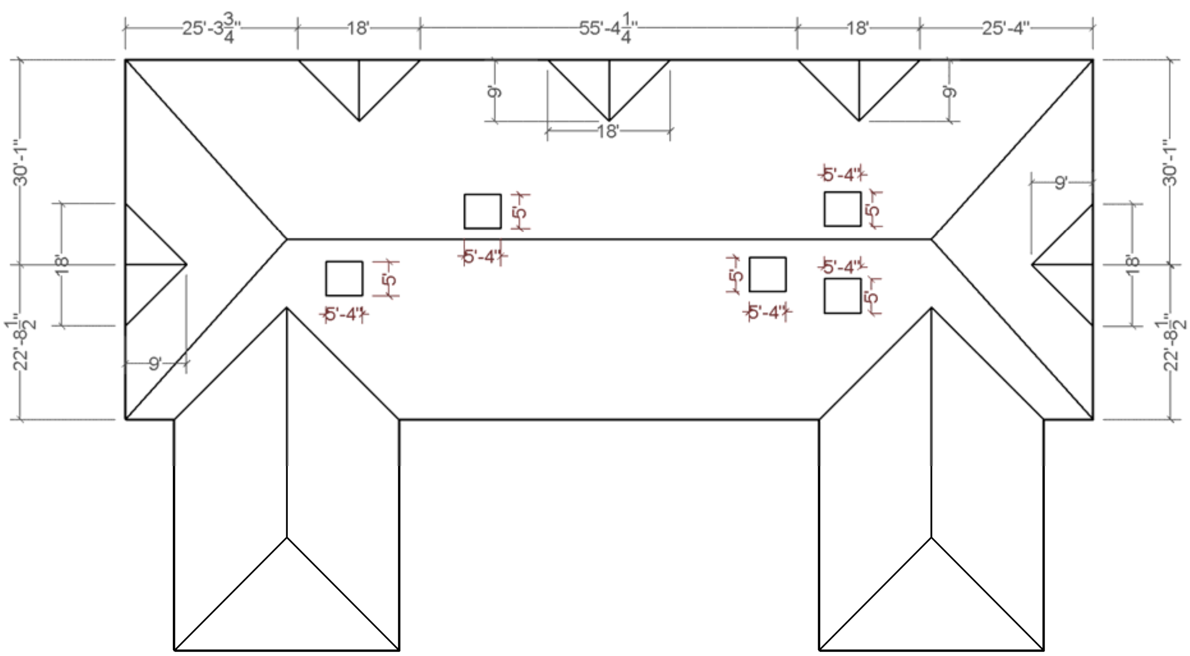


Figure 5.3 Locations of Proposed Dormers and Skylights

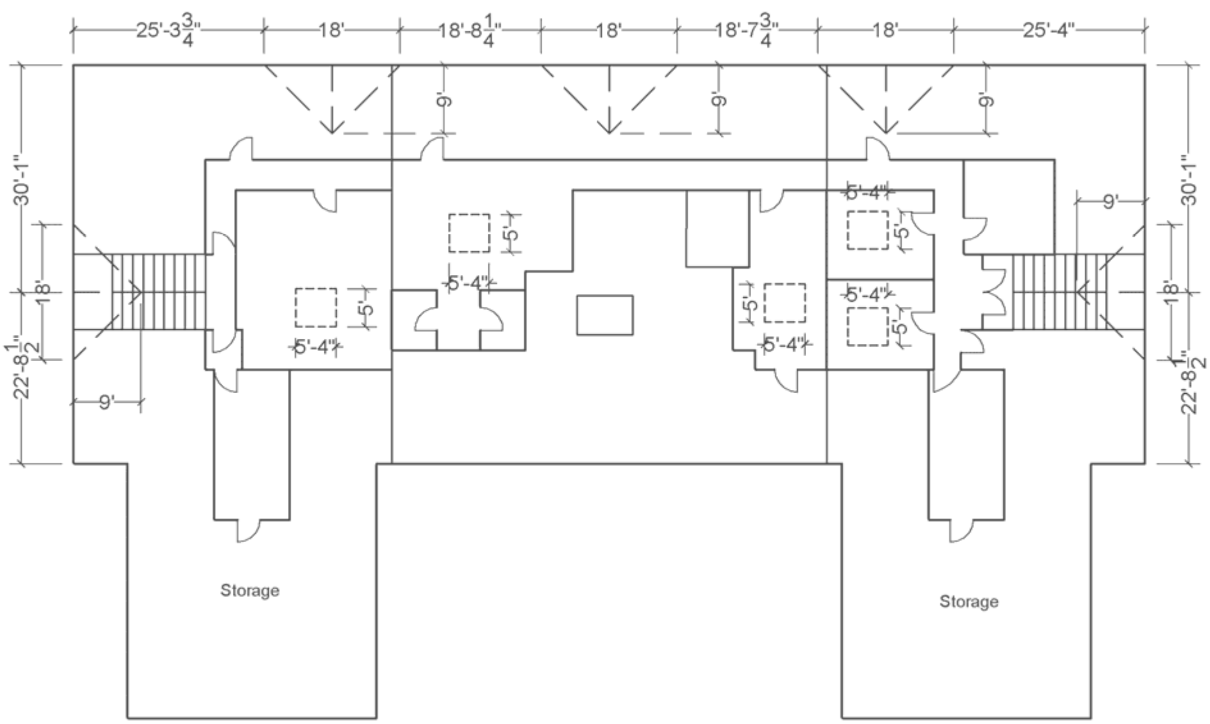


Figure 5.4 Locations of Proposed Dormers and Skylights in Reference to Proposed Floor Plan

5.3 Stair Design

The existing stairs that begin in the basement of Kaven Hall and continue through the first floor to the second floor are U-shaped. The stairs are 4 ft wide and begin at ground level and continue upward to a 5ft x 10ft platform located halfway between the two floors. The second half of the stairs begins at that platform and continues upwards in the opposite direction of the first half and ends at the next floor. These stairs were examined and assumed to be comprised of a ½ in steel pan with a ½in x 12in steel plate on the side which borders the wall and a 12in x 2in x ¼in rectangular box on the other. The treads were assumed to be 12in x 2 in concrete.

For both aesthetics and consistency, it was decided that continuing the design of the existing staircases up to the attic would be best, provided the design is structurally up to code. A loading analysis was performed to determine the maximum live load that could be supported by the existing stair design. A maximum live load of 1500lb/ft was calculated and found to be more than sufficient. The design calculations for the stairs can be found in Appendix B. A copy of the cross sections of the stairs can be found below in Figure 5.5.

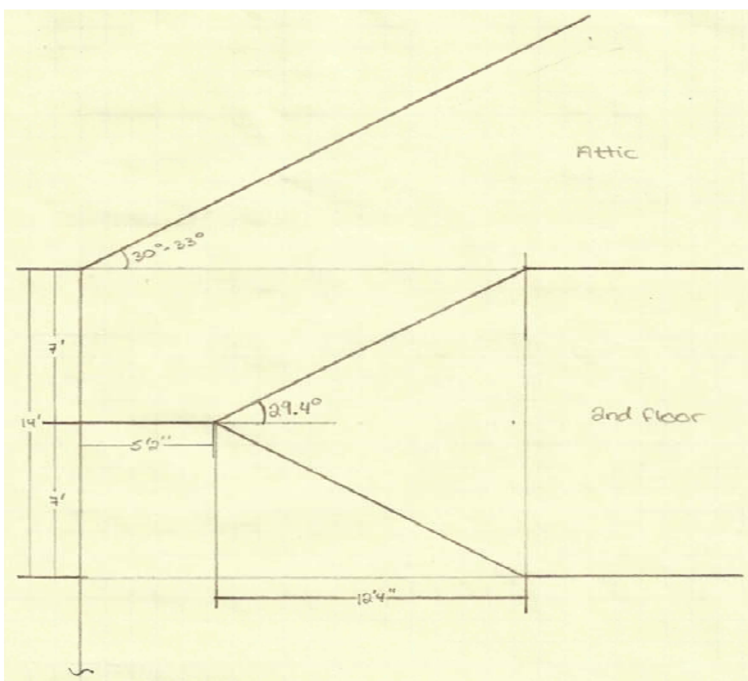


Figure 5.5 Cross Section of Stairs in Reference to Headroom

5.4 Elevator Design

One of the major additions to Kaven Hall as a result of the renovation proposed by this project is the addition of an elevator. Not only will installing an elevator help to bring the building up to code by, allowing handicapped persons to use all floors located in Kaven Hall, it will also be beneficial for moving heavy samples from the labs to the various floors, and vice versa.

Before any work can be done for designing the shaft needed by the elevator, it is first necessary to determine which type of elevator would be most beneficial for this particular situation. According to the Otis Elevator Company, there are several aspects that go into determining the correct elevator, such as; travel distance, the type of building, the number of stops, the required elevator use and speed, while maintaining the available budget. There are many different types of elevators depending on the size, in terms of floors, and type of building that it will be installed in. There are special elevators for hospitals and residential houses along with ones used for high and low-rise buildings and freight elevators for transportation of heavy materials. In this case, a low-rise elevator will be used since there are only four floors in Kaven Hall. The typical low-rise elevator is one that is hydraulically powered; however there are many types of hydraulic elevators. The different low-rise elevators include: holeless hydraulic, roped hydraulic, holed hydraulic and roped holeless hydraulic elevators (Otis, 2008). After receiving sound advice from the Worcester Elevator Company, it was determined that the Roped Holeless Hydraulic Elevator would be best suited for this application.

The Roped Holeless Hydraulic Elevator works when a cantilevered elevator car is lifted by cables that are attached to the cable crosshead, which in turn, is lifted (and lowered) by the dual lifting pistons on either side of the car. There is a need for a machine room on the ground floor, and also a small excavation for the pit underneath the elevator, at minimum height (Stein, Reynolds, 1992). This specific type of elevator is perfect for Kaven Hall because it meets all the requirements needed by the building. Any elevator designed for Kaven Hall will need to reach four stories, approximately 48 feet, have four different stops, need front and rear entrances into the car and withstand a capacity of 2,500lbs, as is typical for an elevator at WPI. The chosen elevator for Kaven Hall fits all these needs as it can reach a maximum height of 60 feet, will allow for six different stops, and can withstand a capacity of up to 5,000lbs. The typical speed for this type of elevator varies from 125fpm to 150 fpm (Otis, 2008). Another reason why the Roped Holeless Hydraulic Elevator is a good fit for Kaven Hall is because these types of elevators are recommended for existing buildings that do not have existing elevators installed (Otis, 2008).

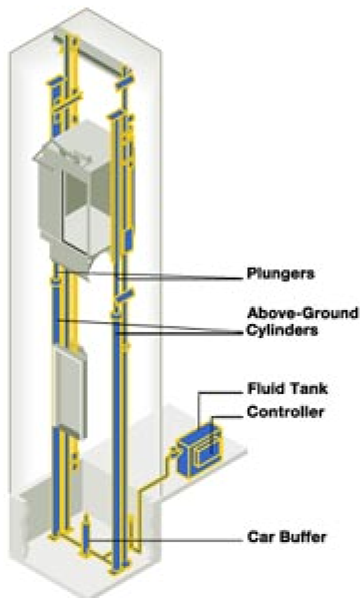


Figure 5.6 Hydraulic Elevator Shaft (Otis Elevator Company, 2008)

The interior of the elevator car must adhere to strict regulations as set by the American with Disabilities Act, ADA. There are mandatory rules for floor area with the elevator cab, button height, call box height, illumination, door location and speed. The minimum dimensions for a two-door elevator are 4.75 feet, from door to door, by 5.67 feet, side to side (ADA407.4.1). The elevator chosen for Kaven Hall has a door-to-door dimension of five and a half feet and a side-to-side dimension of six feet, while maintaining eight feet of headroom. This would make the outer dimensions of the cab to be approximately six feet by six and a half feet (Harris Int. Elevator Inc., 2008). According to the ADA 308, elevator buttons within the cab must maintain a height of no less than 35” and no greater than 54” above the finished elevator floor. These buttons are also required to be either raised or flush with the car’s interior wall and cannot have a diameter less than ¾” at its smallest distance. To meet reach requirements, call boxes cannot be any lower from the finished floor than 15” or any higher than 48” (ADA 308). Also, the illumination in the car must be maintained at no less than five foot candles, or 54 LUX (ADA 407).

Other than the elevator itself, the shaft and the machine room, there are a few very important aspect of a working elevator. These aspects include the buffers, the jack stands and the guide rails. In order to find out which types of buffers, jack stands, safety beam and rails would be needed, the Worcester Elevator Company, W.E.C., was contacted. According to the W.E.C., there are standards for all these items depending on the type of elevator chosen and the maximum loading it can withstand. Since Kaven Hall will be using a Roped Holeless Hydraulic Elevator, holding a maximum loading of 5,000lbs, including its own weight, and a max speed of 150fpm, it was determined that the following objects must account for the following stress:

Car Buffers = 5,800lbs at each of the two buffers.

Jack Reactions = 6,200lbs at each of the two jacks.

Safety Beam = 5,000lbs across length of member.

Guide Rails = 10,500lbs on each vertical rail.

The buffers, jacks, safety beam and rails should then be ordered from the elevator manufacturer according to this information.

There are many restrictions to building an elevator in an existing building. In this specific case, the first restriction is the basement floor level. In order to install an elevator in Kaven Hall, a small exaction will need to be created. The Roped Holeless Hydraulic Elevator however, does not require the typical excavation for an elevator. This type is special because of its unique design. Instead of the average Roped Hydraulic Elevator that consists of one single-section telescoping piston underneath the elevator car, the Roped Holeless Hydraulic Elevator uses two dual lifting pistons on either side of the passenger car. There will still be a need for excavation in order for the floor slab to withstand the loading from the elevator and the concrete block shaft that will encompass the elevator.

Moving from the ground up, the second challenge includes the design and installation of a machine room that would need to be located directly next to the elevator shaft. As required by the American Disability Act, this machine room must have dimensions of no less than six feet by seven feet and contain two entrances. Each doorway must have the required width of three feet. One door shall open into the hallway and the other into the shaft of the elevator. The proposed location of this machine room is currently occupied by some cabinets and counter, both of which can easily be relocated.

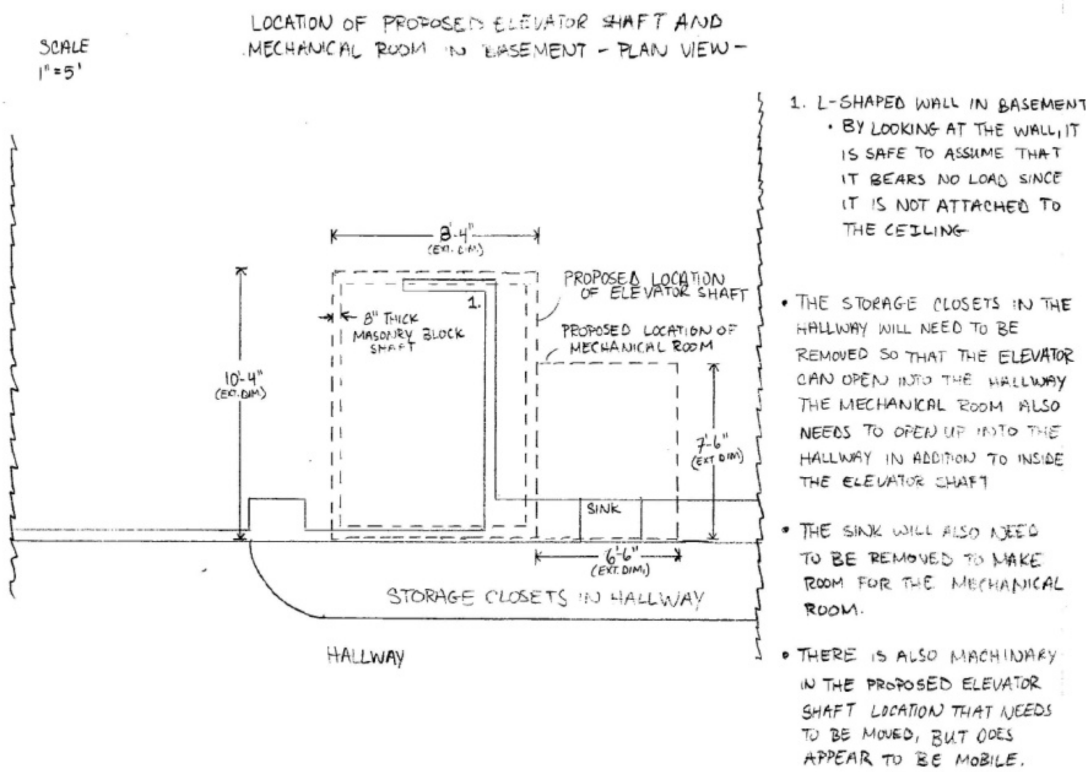
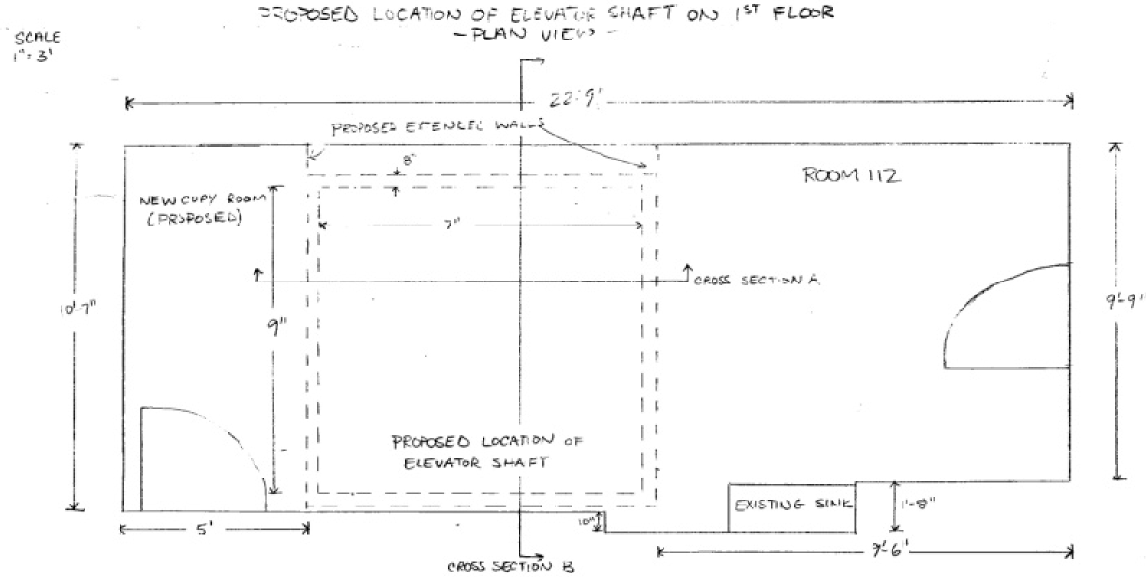


Figure 5.7 Proposed Location of Elevator Shaft in Basement

PROPOSED LOCATION OF ELEVATOR SHAFT ON 1ST FLOOR
– PLAN VIEW –



- ROOM 112 (COPY ROOM) ON FIRST FLOOR WILL BE DRASTICALLY REDUCED AND MOVED AROUND DUE TO PROPOSED SHAFT THAT WILL SPLIT THE EXISTING ROOM

- THE SHAFT WILL SPLIT THE ROOM INTO TWO SEPERATE SECTIONS. ROOM 112 WILL NOW HAVE DIMENSIONS OF 9'-9" x 9'-6", ROUGHLY 92SF. THE NEW COPY ROOM WILL HAVE DIMENSIONS OF 5' x 10'-7", ROUGHLY 53SF.

Figure 5.8 Proposed Location of Elevator Shaft on 1st Floor

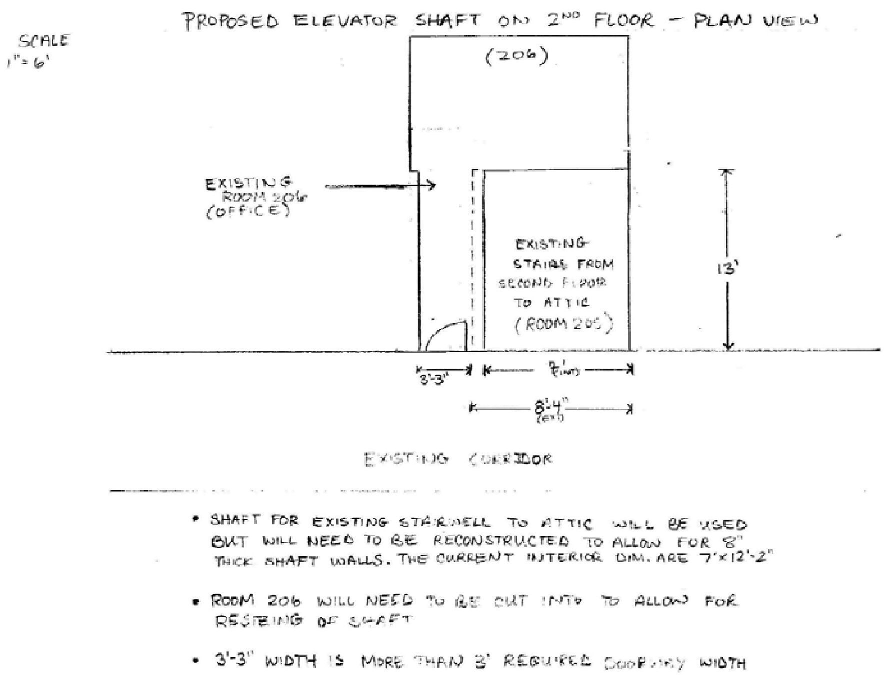


Figure 5.9 Proposed Location of Elevator Shaft on 2nd Floor

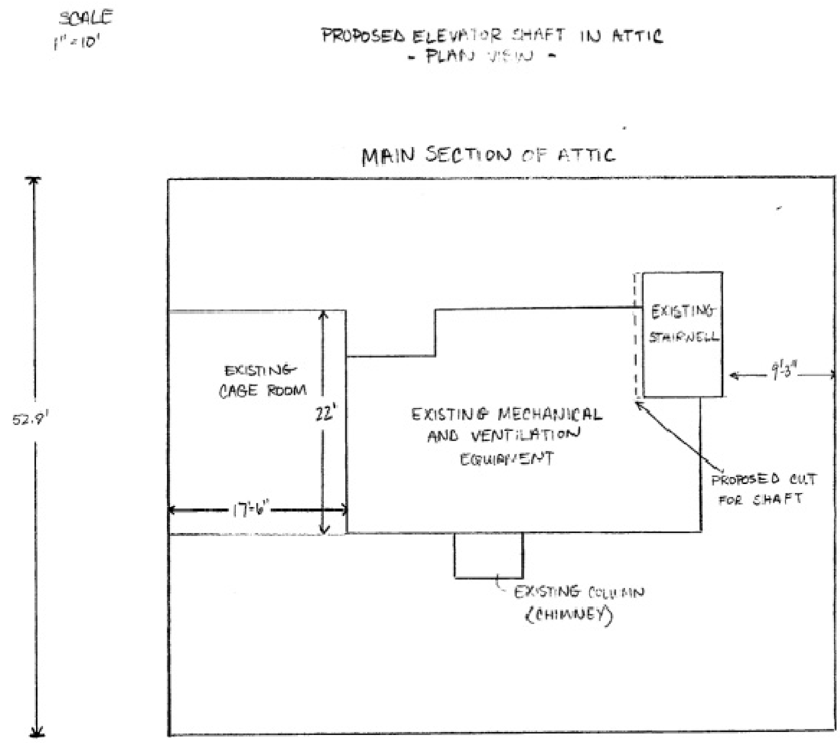


Figure 5.10 Proposed Location of Elevator Shaft in Attic

After determining the dimensions of the elevator car, the dimensions required for the elevator shaft can be determined. Since an elevator with outer dimensions of 6 feet by 6.5 feet was chosen for Kaven Hall, a shaft of size nine feet by seven feet would be sufficient. According to the American Concrete Institute's Building code Requirements for Masonry Structures, any masonry block, load-bearing, wall shall have a minimum thickness of eight inches (ACI 7.6). Masonry blocks were decided to be the best option for building the shaft for this particular situation, especially since they are eight inches thick. They have dimensions of 8"x8"x16". The inner dimensions of the shaft were determined to be nine feet by seven feet, making the outer dimensions ten feet four inches by eight feet four inches, due to the thickness of the wall. The outer dimensions of the shaft are also the dimensions of the cuts that need to be made into each of the existing floor slabs. Due to the cut through the concrete waffle floor slab, the concrete block wall will then have to withstand the loading of the slab previously withstood by the beams and girders that were cut out. The total loading and design calculations for the elevator can be found in Appendix B: Structural Analysis and Design.

In order to withstand the total loading of 67psi, the current slab in the basement must be removed and rebuilt. A Roped Holeless Hydraulic Elevator does not require the typical pit volume underneath the ground floor that other elevators do. It does however need a pit, just a smaller one that normal (Otis, 2008). The bottom of the pit needed for this elevator would need to withstand the factored loading of 67 psi. This pit will need to be three feet deep; from the top of the basement floor slab to the top of the pit slab supporting the elevator and shaft. A cast-in-place reinforced concrete slab that is two feet thick will be able to withstand this new loading (Wang, Salmon, Pincheira, 2007).

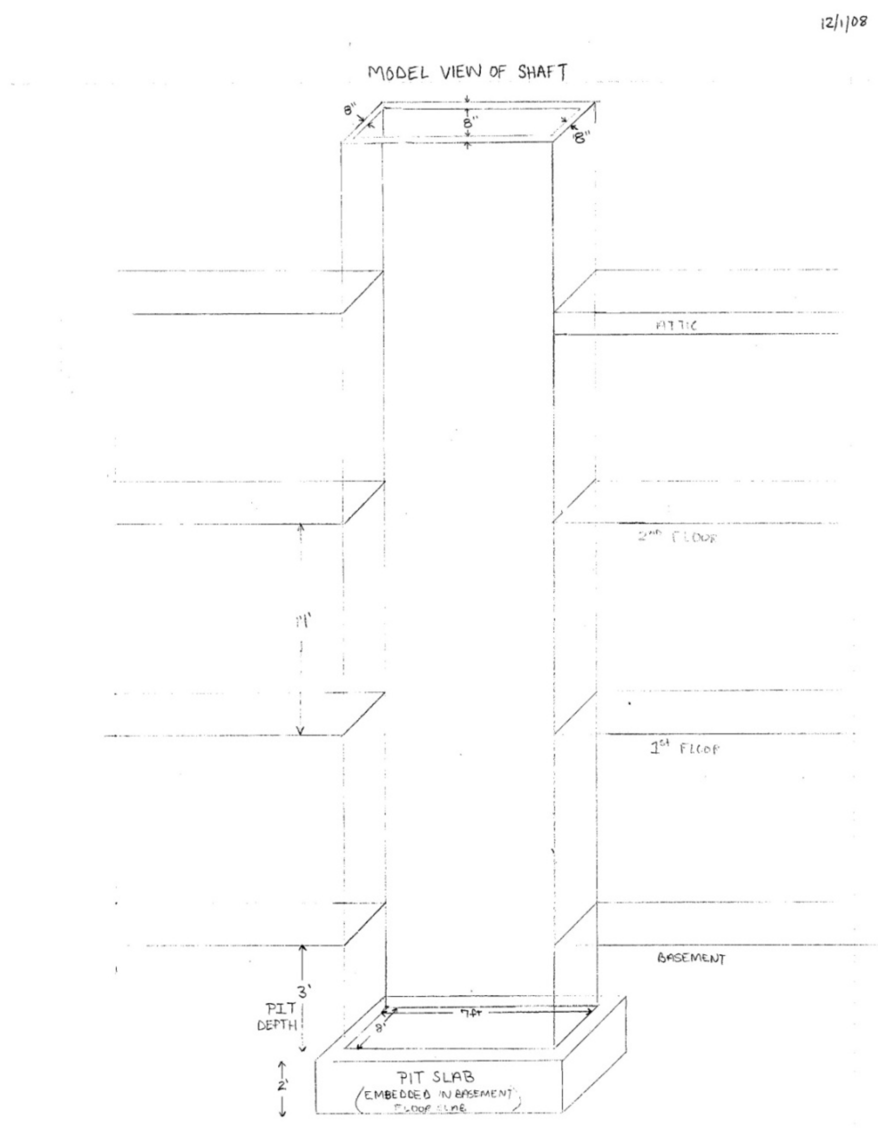


Figure 5.11 Model View of Elevator Shaft

5.5 Dormer Design

Currently, there are four existing gable dormers on the roof-top of Kaven Hall (a typical gable dormer can be seen in Figure 5.12 along with other commonly-used dormers.) There is one directly above each of the existing stairwells on the north and south ends of the building. There are two additional dormers, both of which are on the east side of the building, facing away from campus. These dormers can all be seen from the plan view representation in Figure 5.13. None of these dormers, however, are used to provide the attic with the necessary natural lighting that is needed. The one accomplishment these dormers offer is the ventilation provided by each dormer.

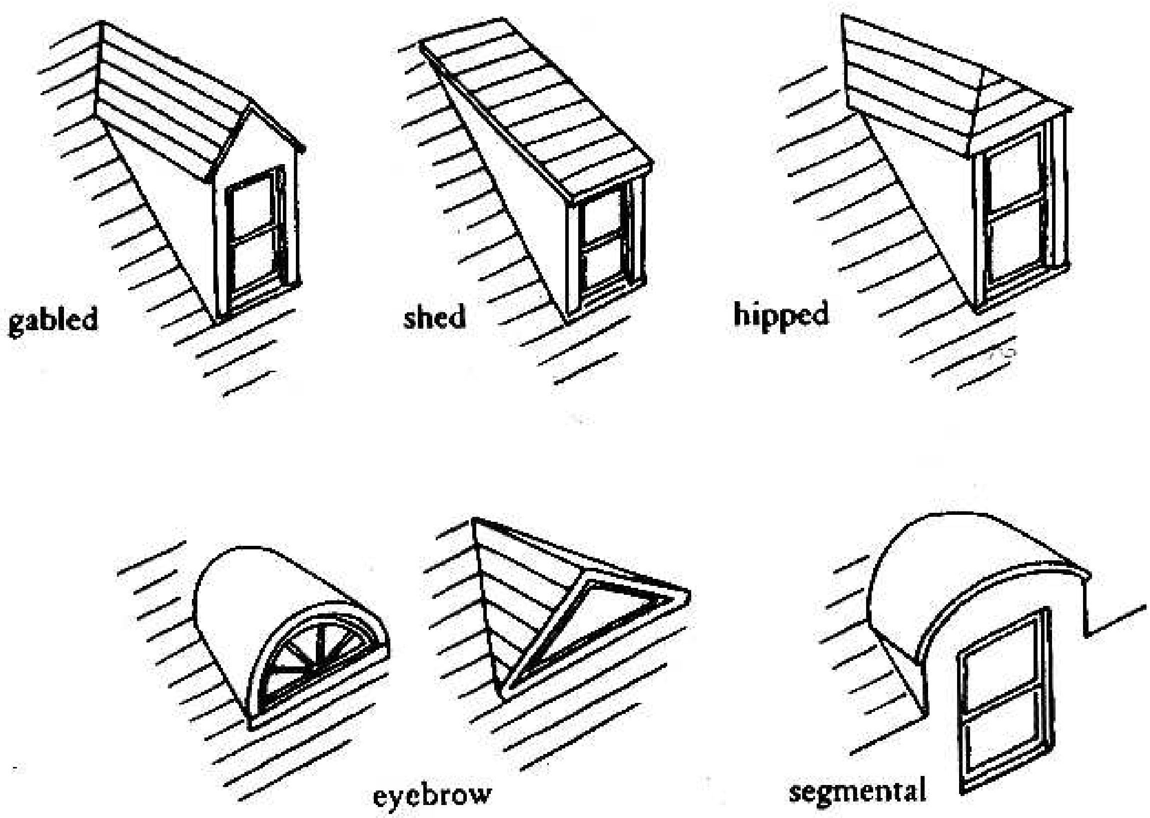


Figure 5.12 Dormer Styles

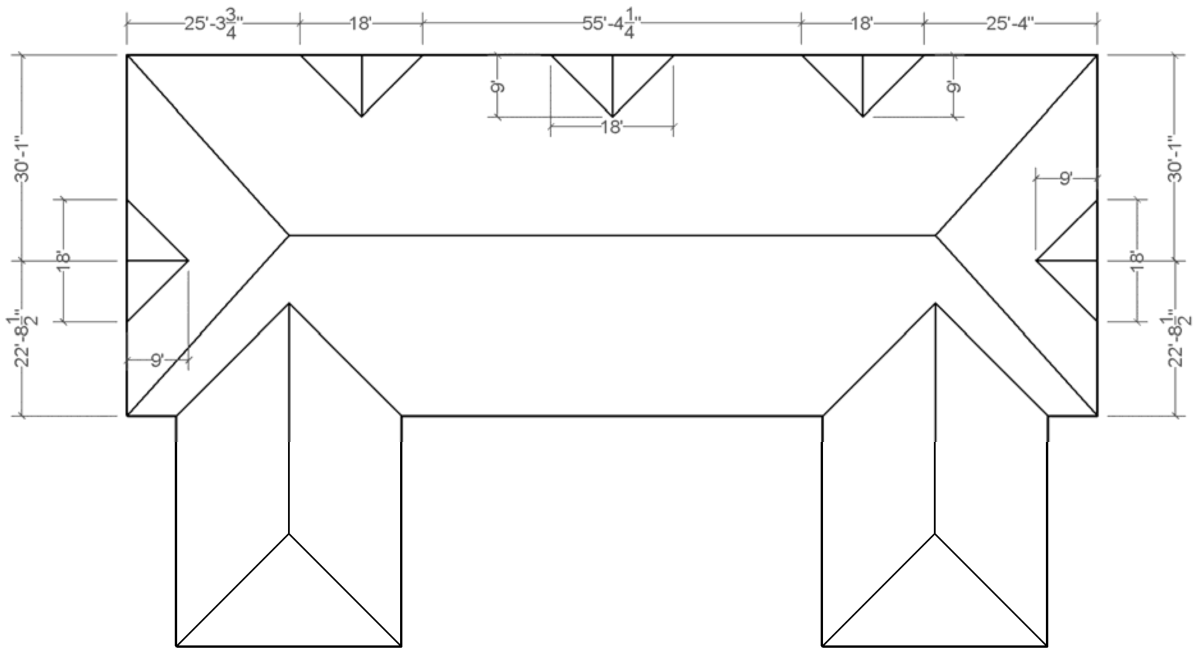


Figure 5.13 Proposed Dormer Locations

Dormers are installed for all sorts of reasons. They may be installed to provide more illumination in a room or to add additional floor space to the top floor in a building. They may also be designed and installed simply for aesthetic purposes. The renovation of the attic in Kaven Hall requires such dormers for almost all of the afore-mentioned reasons. Much more natural lighting is need in the attic, as well as natural ventilation.

While there are two dormers directly above each of the existing stairs that extend from the basement to the second floor, they do not provide enough height clearance for the proposed stairs. The proposed stairs shall extend the existing stairs from the second floor into the attic, as to provide sufficient means of egress as set forth in the *CMR*. These dormers need to be raised, to allow for the minimum amount of head clearance for any means of egress, which is seven feet (780 *CMR* 1003.2). As renovation takes place on these dormers, gable style dormer will continue to be used.

One additional dormer will also need to be designed and installed in the main room of the attic. The main reason for the installation of this dormer is to allow natural lighting and ventilation into this area of the attic. The dormer will be installed directly in the middle of the two existing dormers and also directly in the middle of the main room. Since the two dormers at the south and north ends of the building will be renovated and will maintain the gable style dormer, this dormer shall be designed using the same style. The two existing dormers will remain but will still only be used for aesthetic purposes only. The dormers will be supported by an upper and lower header that will be 2" x 10" Douglas Fir rafters. The width of the dormers will remain 18 feet including the newly designed one, and the top of the peak will be approximately ten feet from the base of the dormer. The supporting rafters will be doubled with the existing 2" x 12" Douglas Fir rafters. The design calculations in Appendix B: Dormer Design shows the new supports are sufficient.

5.6 Skylight Design

The final stage of the design process involves the installation of skylights on specific parts of the roof for natural lighting purposes. There are currently dormers in the existing roof structure, but are only for aesthetic purposes and provide no natural lighting to the attic. This is the main reason that skylights are necessary in the redesign of the roof of Kaven Hall. Currently there are no skylights on the roof and to meet lighting requirements five new skylights will be installed on the roof.

The type of skylight to be designed is a typical flat skylight that if necessary can be opened for ventilation purposes. The skylight size should never be more than 5% of the floor area and no more than 15% of the room's total floor area for spaces with few to no windows. The skylight provided will be at a 30 degree slope and use a single glazing aluminum frame with a metal spacer. In order to determine heat loss it is found that this type of skylight will supply a U-factor of 1.9. A U-factor is the rate at which a window, door, or skylight conducts non-solar heat flow into a building or room. It is usually expressed in units of Btu/hr-ft^2-F. For skylights, windows, or glass doors, a U-factor may refer to just the glass or glazing alone. Glazing is when multiple glass panes or "lites" are assembled into units, which are commonly referred to as "insulated glass". Installed skylights typically have a higher effective U-factor than windows of the same materials, construction, and size, resulting in 35%-45% greater heat losses during cold weather. This is caused by three main factors convection, which is the movement of molecules within fluids, radiation, and the supporting frame. Below in figure 5.14 are a sample of different skylights, the first is the design that was used.

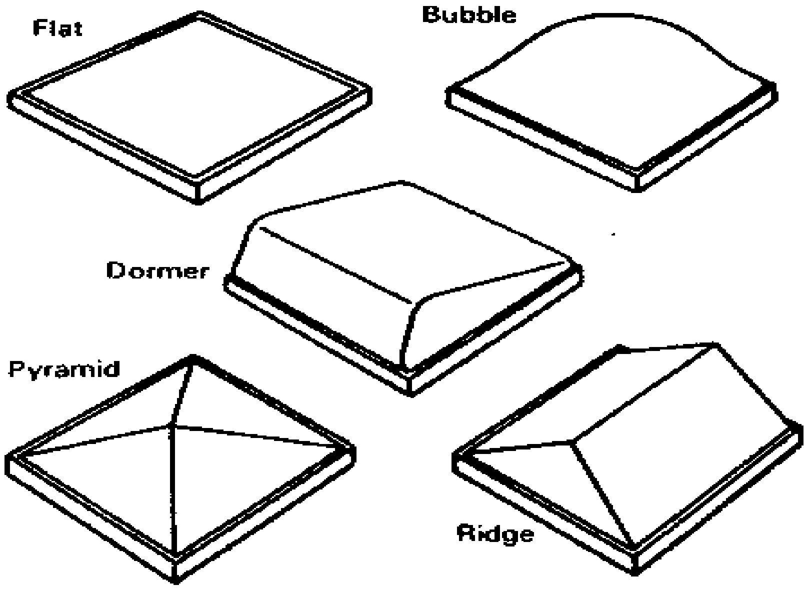


Figure 5.14 Skylight Styles

The design for the structural support of the skylights is shown in Appendix B: Structural Analysis and Design. Every skylight will have the same dimensions. The skylights will be located over the rooms' tech suite 1, tech suite 2, the individual study area, the lounge area, and the conference room. The skylights will all have the dimensions of 5'-4" x 5'. The design of the skylights involved a structural timber analysis for the supports that will make up for the rafters being cut when the skylights are installed. The upper header will support the distributed loads carried out by the cut rafters through the sidewalls down to the lower header and then distributed to the existing rafters. The wooden member to be used for the headers is determined to be 2"x6" Douglas Fir rafters. The skylight locations on the Kaven Hall roof are shown in Figure 5.15 on the next page. Figure 5.16 shows the framing and supports of the designed skylight.

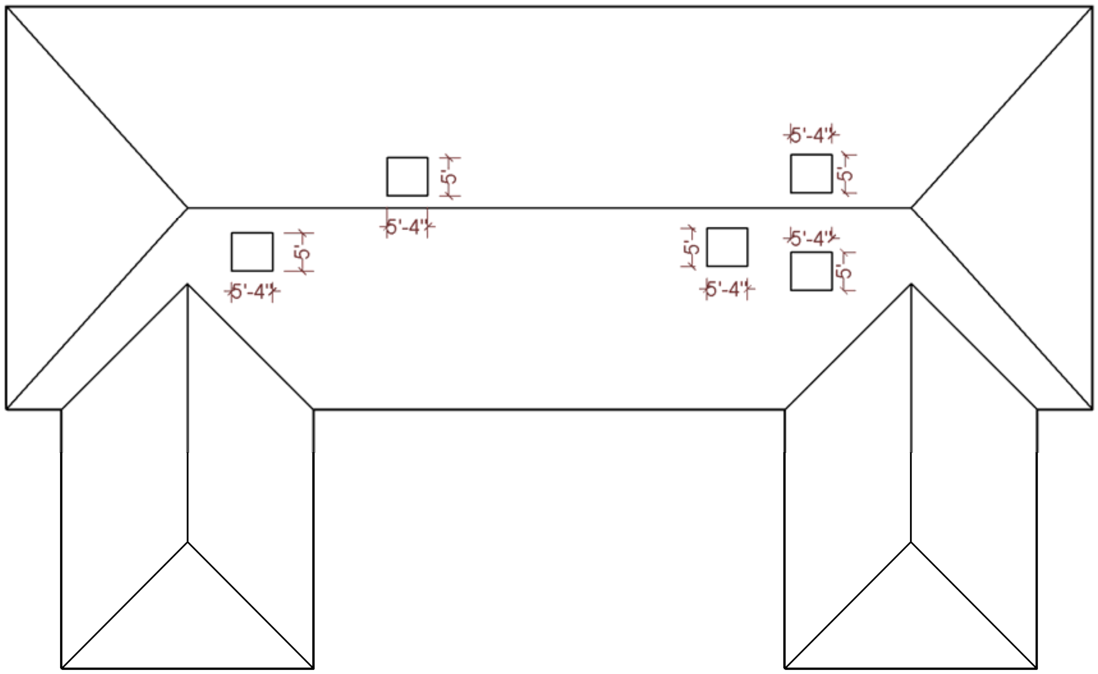


Figure 5.15 Proposed Skylight Locations

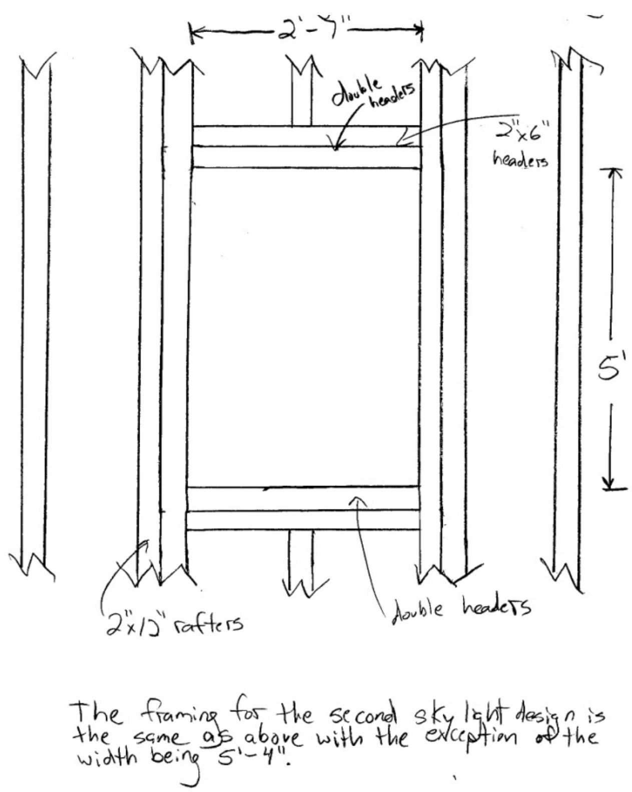


Figure 5.16 Proposed Skylight Framing

The re-structuring of the roof, installation of stairwells, and the design of the elevator were the most costly and difficult aspects to the renovation of the attic. These changes were necessary throughout the project in order to bring the building up to standards for the *ADA* code in order for the entire building to be handicap accessible. The building was also brought up to code in order to be compliant with the *CMR*. With the new installation of the two stairwells students will now have access to two entrances on either side of the attic. The elevator will provide access to the injured or handicap, and can also provide service for students with large projects to be transferred. The dormers will provide the appropriate amount of natural light into the stairwells and hallway, while the skylights will be able to illuminate most of the rooms used by students and faculty. With these new renovations and changes to the attic and rest of the building, the student and faculty will now be able to fully enjoy the new facilities installed in the Kaven Hall attic.

6 Cost Estimate and Scheduling

In preparing a cost estimate and schedule for a project, it is first important to know what the project entails. The work to be completed must be quantified and a list of all construction activities to take place must be created. From there, a cost estimate for the project can be developed by assigning costs to the calculated quantities. For each activity, the amount of time needed for completion must be determined and the activities must be arranged in the order in which they need to be completed. From the durations and sequence of activities, a schedule can then be developed to determine how long the project will take to complete.

6.1 Quantity Take-Off

In order to determine the quantities of the work to be completed, the work was first divided into three categories: demolition, exterior construction, and interior construction. For the demolition portion of the renovation, each concrete slab cuts, roof cuts, and walls to be demolished needed to be quantified. These demolition quantities are shown in Table 6.1.

Table 6.1 Demolition Quantities

Demolition	Quantity	Unit
Attic Stairs (total for 2 cuts)	40	sq.yd.
Attic Elevator	1.5	sq.yd.
2nd Floor Elevator	9	sq.yd.
1st Floor Elevator	9	sq.yd.
Basement Elevator	3	cy
Roof Cuts (2 dormers, 5 skylights)	595	lf
Hallway cuts (total for 2 cuts)	40	lf
Existing Attic Stair Shaft	120	cf
Cage room	74	lf
Demolition Waste	25	ton

The exterior construction portion of the renovation includes the construction of dormer walls, roofs, and windows as well as the installation of skylights. The quantities of each of these items can be seen in Table 6.2.

Table 6.2 Exterior Construction Quantities

Exterior	Quantity	Unit
Roof Rafters	375	Sq.ft.
Slate Shingles	375	Sq.ft.
Exterior Walls	100	Sq.ft.
Window (8'x4'-6")	2	Ea.
Skylight (5'x5')	5	Ea.

The interior construction portion of the renovation consists of the installation of stairs, an elevator, partition walls, ceilings, doors, flooring, and bathroom fixtures as well as all the painting. Table 6.3 lists all of the elements of the interior construction along with their respective quantities.

Table 6.3 Interior Construction Quantities

Interior	Quantity	Unit
Stairs (with landing)	2	Ea.
Hydraulic Elevator	1	Ea.
CMU (Elevator Shaft)	1950	Sq.ft.
Partition Walls	4650	Sq.ft.
Metal Door (single)	2	Ea.
Metal Door (double)	1	Ea.
Wood Doors	16	Ea.
Roof Insulation	11800	Sq.ft.
Ceilings	11800	Sq.ft.
Paint (walls and ceilings)	19000	Sq.ft.
Carpet	2400	Sq.ft.
Acrylic	1050	Sq.ft.
Tile	100	Sq.ft.
Toilets	2	Ea.
Sinks	2	Ea.
Light Fixtures	21	Ea.

6.2 List of Activities

The second step in the cost estimating and scheduling process was the development of a list of activities. This list of activities was made up of every single event and process that will need to occur in order to start and complete the proposed attic renovation. In addition, the order in which these activities must take place needed to be determined, as well as the length of time necessary to complete each activity. These durations were calculated using the quantities listed in Section 6.1 as well as productivity rates found in Building Construction Cost Data. Table 6.4 shows the list of activities for the proposed renovation organized by the standard construction divisions.

Table 6.4 List of Activities

		Duration	Preceded by
Division 1	General Requirements		
1-1	Start	0	
1-2	Order and Receive Equipment	30	1-1
1-3	Disposal of Demolition Waste	1	2-7, 2-9
1-4	Clean Site	2	16-3, 15-5,14-3
1-5	Hand Over to Owner	0	1-4
Division 2	Site Construction		
2-1	Mobilization	30	1-1
2-2	Demo Floor for East Stairs	1	1-2
2-3	Demo Floor for West Stairs	1	5-2
2-4	Slab on Grade Demo For Elevator	1	1-2
2-5	First Floor Slab Cut for Elevator	1	2-4
2-6	Second Floor Slab Cut for Elevator	1	2-5,2-8
2-7	Attic Slab Cut for Elevator	1	2-6
2-8	Demo Existing Attic Stair Shaft	6	1-2
2-9	Roof Cuts for Dormers and Skylights	10	5-3
2-10	Wall Cuts for Hallway	1	6-2, 8-2
2-11	Demo Cage Room	1	6-2, 8-2
2-12	Temporary protection during construction		1-2
Division 3	Concrete		
3-1	Repair East Stair Cut	1	2-2
3-2	Repair West Stair Cut	1	2-3
3-3	Repair Slab on Grade Cut	1/2	2-4
3-4	Repair 1st Floor Slab Cut	1/2	2-5
3-5	Repair 2nd Floor Slab Cut	1/2	2-6
3-6	Repair Attic Floor Slab	1/2	2-7
Division 4	Masonry		
4-1	Erect Elevator Shaft in Basement	1/2	3-3, 2-7

4-2	Erect Elevator Shaft on First Floor	1/2	4-1, 3-4
4-3	Erect Elevator Shaft on Second Floor	1/2	4-2, 3-5
4-4	Erect Elevator Shaft on Attic Level	1/2	4-3, 3-6
Division 5	Metals		
5-1	Order and Receive Stairs	90	1-1
5-2	Install East Stairs	3	5-1, 3-1
5-3	Install West Stairs	3	3-2
Division 6	Wood and Plastics		
6-1	Order and Receive Lumber	15	1-1
6-2	Construction of Dormers	15	6-1, 2-9
6-3	Interior Wall Framing	12	2-10, 2-11, 15-1
Division 7	Thermal and Moisture Protection		
7-1	Order and Receive Roofing	15	1-1
7-2	Installation of Dormer Roofing	5	7-1, 6-2
7-3	Order and Receive Insulation	15	1-1
7-4	Insulation of Roof	8	7-3, 2-9
Division 8	Doors and Windows		
8-1	Order and Receive Skylights	30	1-1
8-2	Installation of Skylights	2	8-1, 2-9
8-3	Order and Receive Doors and Frames	30	1-1
8-4	Install Door Frames	1	8-3, 9-2
8-5	Install Doors	1	9-5, 9-6, 9-7
Division 9	Finishes		
9-1	Order and Receive Drywall	15	1-1
9-2	Install Partition Wall Drywall	3	9-1, 6-3, 15-2, 16-1, 15-3
9-3	Install Ceiling Drywall	8	9-1, 15-3, 7-4
9-4	Order and Receive Flooring	15	1-1
9-5	Install Acrylic Flooring	2	9-4, 8-4
9-6	Install Carpet Flooring	2	9-4, 8-4
9-7	Install Tile Flooring	1	9-4, 8-4
9-8	Paint	8	9-3, 8-5
Division 14	Conveying Systems		
14-1	Order and Receive Elevator	120	1-1
14-2	Install Elevator	10	14-1, 4-4, 2-8
14-3	Install Elevator Doors	2	14-2
14-4	Elevator electrical system	22	3-4

14-5	Elevator commissioning	23	3-4
Division 15	Mechanical		
15-1	Removal of Fire Sprinkler System	5	6-2, 8-2
15-2	Rough In Bathroom Plumbing	3	15-1
15-3	Install New Fire Sprinkler System	5	15-1
15-4	Order and Receive Bathroom Fixtures	15	1-1
15-5	Install Bathroom fixtures	1	15-4, 9-8
Division 16	Electrical		
16-1	Utility Installation	18	15-1
16-2	Order and Receive Lighting	15	1-1
16-3	Install Lighting	2	16-2, 9-8

6.3 Cost Estimate

Through the use of RS Means CostWorks cost estimating software and the RS Means Building Construction Cost Data (2006) book, costs were assigned to the quantified work to be done. The costs for each of the activities are shown in tables 6.5 (demolition), 6.6 (exterior construction), and 6.7 (interior construction. The per-unit costs were multiplied by the quantities and their products were added together to determine the sub-total cost of each of the three categories of the renovation. Each of these sub-totals was then assigned a mark-up percentage based on the existing conditions. For the demolition costs there must be a 200% mark-up in the final price and for construction, a 50% mark-up. The sum of these sub-totals and mark-ups was then assigned a 50% mark-up to account for existing conditions, inflation, contractor profit, and subcontractor profits. Through these steps, the cost of the proposed renovations was calculated to be approximately $1,820,000.

Table 6.5 Demolition Costs

Demolition	Quantity	Unit	Cost per Unit ($)	Total Cost ($)
Attic Stairs (total for 2 cuts)	40	sq.yd.	9	347
Attic Elevator	1.5	sq.yd.	9	13
2nd Floor Elevator	9	sq.yd.	9	78
1st Floor Elevator	9	sq.yd.	9	78
Basement Elevator	3	cy	86	258
Roof Cuts (2 dormers, 5 skylights)	595	lf	2	1,089
Hallway cuts (total for 2 cuts)	40	lf	2	92
Existing Attic Stair Shaft	120	cf	2	263
Cage room	74	lf	3	238
Demolition Waste	25	ton	90	2,250
			Sub Total:	4,705
			200% Mark-up	9,411
			Total	14,116

Table 6.6 Exterior Construction Costs

Exterior	Quantity	Unit	Cost per Unit ($)	Total Cost ($)
Roof Rafters	375	sq.ft.	16	5,824
Slate Shingles	375	sq.ft.	9	3,233
Exterior Walls w/ Brick Veneer	90	sq.ft.	31	2,780
Window (8'x4'-6")	2	ea.	1095	2,189
Skylight (5'x5')	5	ea.	3623	18,113
			Sub Total	32,138
			50% Mark-Up	16,069
			Total	48,207

Table 6.7 Interior Construction Costs

Interior	Quantity	Unit	Cost Per Unit ($)	Total Cost ($)
Stairs (with landing)	2	ea.	21,206	42,413
CMU (Elevator Shaft)	1950	sq.ft.	32	62,790
Elevator	1	ea.	200,000	200,000
HVAC	1	ea.	242,000	242,000
Utility Wiring	582	lf	100	58,200
Fire Sprinkler System	3550	sq.ft.	7	24,850
Partition Walls	4650	sq.ft.	6	25,715
Metal Door (single)	2	ea.	971	1,942
Metal Door (double)	1	ea.	1,728	1,728
Wood Doors	16	ea.	1,066	17,062
Roof Insulation	11800	sq.ft.	1	16,284
Ceilings	11800	sq.ft.	2	26,786
Paint (walls and ceilings)	19000	sq.ft.	1	18,240
Carpet	2400	sq.ft.	4	10,708
Acrylic	1050	sq.ft.	8	8,789
Tile	100	sq.ft.	11	1,107
Toilets	2	ea.	1,435	2,869
Sinks	2	ea.	1,176	2,351
Light Fixtures	21	ea.	148	3,108
			Sub Total	766,941
			50% Mark-Up	383,471
			Total	1,150,412

6.4 Scheduling

After the list of activities was completed, each activity, along with its duration and relationships to other activities, was inputted into Primavera construction scheduling software. Once all the information was inputted, the software created a schedule of all the activities and displayed the schedule in bar-chart form. This schedule can be seen in Figure 6.1. The activities which are represented by red bars are critical activities, meaning that any delay or acceleration in their progress will cause an equal delay or acceleration in the amount of time the renovation will take to be completed. The activities represented by the green bars are non-critical activities, meaning there can be some delay in their progress without affecting the overall duration of the renovation.

Through Primavera, the amount of time the renovation will take from start to finish was found to be 150 days. Since demolition and construction would be highly disruptive to the classes which take place in Kaven Hall, it was decided that demolition would begin on May 6th, the day after classes end. Given that start date for the demolition portion of the renovation, the majority of the renovation would be completed by the start of the fall semester (the last week of August). The only renovation activities which would overlap the start of the fall semester would be painting, the installation of bathroom fixtures and lighting, and the cleaning of the site. None of these activities would be disruptive to any classes being held within Kaven Hall at that time.

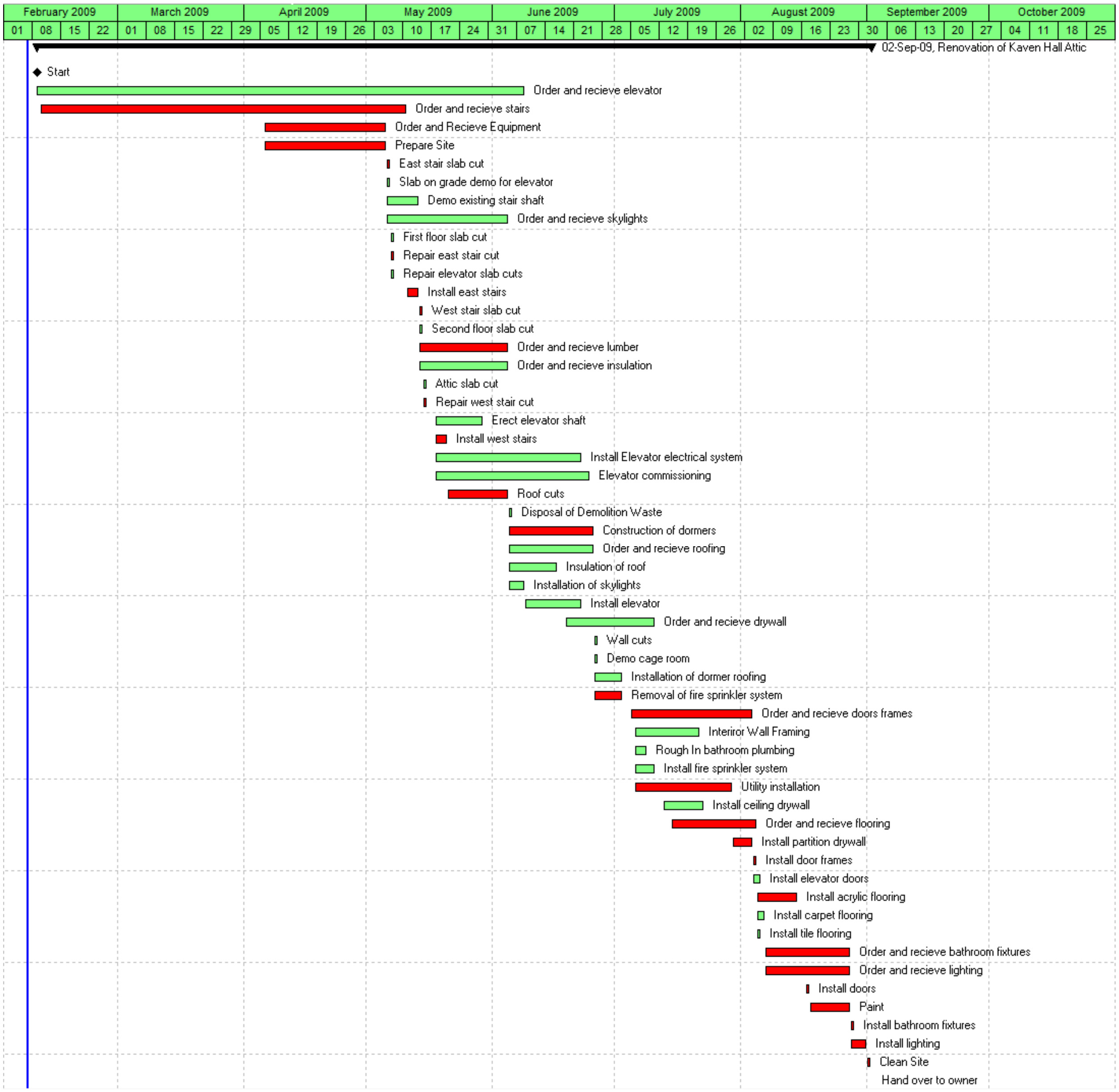


Figure 6.1 Schedule Developed Using Primavera

7 Conclusions and Recommendations

7.1 Conclusions

The main purpose of this project was to devise a renovation plan that would produce a cost effective method that creates additional space for the Kaven Hall attic. The floor layout for the attic was decided based on the opinions of the students and faculty from the surveys given. To go about this process, five activities needed to be accomplished. The existing conditions of the attic had to be considered by surveying and measuring the main components of the attic. The next step was to review the Code of Massachusetts Regulations and the American Disabilities Act in order to decipher what changes needed to be made in the attic in so that these codes would comply. A renovation plan was then proposed based on code compliance and the needs of the CEE department in order to formulate a floor layout for the Kaven Hall attic. Once the proposal was made all structural elements of the proposal were designed which included: the concrete floor slab, the roof, the stairs, elevator shaft, dormers, and skylights. The last component for the renovation process was to develop a project schedule and cost estimate of the work needed to be performed.

The new attic layout can be found in figure 4.3. The new additions to the attic includes two stair cases on the west and east side of the building, as well as an elevator where the existing stairs were located. The roof underwent many changes also with the design of dormers and skylights implemented into the proposed changes. The final floor layout consisted of three technical suites, individual study area, a lounge space, two TA offices, bathrooms, and a conference room. The proposed renovation was estimated to cost $1,820,000 and was estimated to take approximately 150 days to complete.

7.2 Recommendations

The first recommendation we would have for any future projects done on this subject would be to start early. Before A-term even begins, previous MQPs and the floor plans should be located and reviewed. Once the term begins, the existing conditions should be determined and floor plans formulated. The best way to survey the existing condition would be to get a laser distancemeter. This is a tool that automatically measures long distances without the use of a tape measure. It would come in very handy, the tape measure we used proved to be inaccurate for longer distances and this is the solution. Once this is done, code compliance research should begin. In order to finish this project on time, another important procedure to follow would be a schedule detailing when every step needs to be completed by. This schedule should be made during A-term and followed as closely as possible throughout the duration of the project.

Auto-CAD and Primavera are two programs that will be used quite often. The Auto-CAD drawings take intricate detail and should not be over looked or procrastinated until later. Whenever a drawing is required, it should be processed right away to avoid confusion later. As for Primavera, we were required to get permission from the HelpDesk, which was not an easy task. Get permission as soon as you can even though the program will not be used until D-term and be certain that you have full access so that when it comes time to do the scheduling, you will be able to. Also, after any activity is done, a write-up should be formulated. Everything done should be recorded in one way or another as it is completed because waiting till the end to try and do so will result in failure.

References

Retrieved March 2009, from ESP Energy Co.: http://www.espenergy.com/foam_board_insulation.htm

Retrieved 2008, from Otis Elevator Co.: http://www.otis.com

Americans with Disabilities Act Requirements. (1996).

Beaudin, L. F. (1995). *Kaven Hall, MQP.* Worcester: WPI.

Company, R. M. (1995). *Building Construction Cost Data.*

Crey M. Brodeur, P. C. (2003). *Renovation of the Kaven Hall Attic, MQP.* Worcester: WPI.

CRSI Design Handbook. (1996). Illinois: Concrete Reinforcing Steel Institute.

Donald E. Breyer, K. J. (1999). *Design of Wood Structures ASD Fourth Edition.* New York: McGraw-Hill.

Fitzgerald, R. (n.d.). WPI. (C. M. Farrell Jr., & S. Kennedy, Interviewers)

Galvin, F. W. (2001). Commonwealth of Massachusetts State Building Codes, Sixth Edition. Massachusetts, United States of America.

Harris International Elevator Company. (n.d.). Retrieved from Harris Companies: http://www.harriscompanies.com/images/HarrisInternational.htm

Incropera, D. B. (2007). *Fundamentals of Heat and Mass Transfer.* John Wiley and Sons,Inc.

MacGregor, D. (1997). *Air Conditioning Kaven Hall, MQP.* Worcester: WPI.

National Design of Specifications for Wood Construction. (2001). American Forestry and Paper Association.

Salter, C. (2008, October). WPI Facilities. (C. M. Farrell Jr., Interviewer)

Schwartz, M. (1997). *Basic Lumber Engineering for Builders.* California: Craftsman Book Company.

Stein, & Reynolds. (1992). *Mechanical and Electrical Equipment for Buildings, Ninth Edition.* Wiley and Sons, Inc.

The Masonry Standards Joint Committee. (1992). *Building Code Requirements for Masonry Structures (ACI 530-92/ASCE 5-92/TMS 402-92).*

Wang, Salmon, & Pincheira. (2007). *Reinforced Concrete Design.* T. Crowell.

Appendix A: Surveys and Responses

A1: Student Survey

Renovation of the Kaven Hall Attic Student Survey

As part of our MQP, we are researching the type(s) of space needed by the Civil Engineering Department. Your help is greatly appreciated. Please rank the following spaces from 1 to 5, 1 being the most needed, 5 being the least needed.

Tech Suites _______

Conference Rooms _______

Lounge/Relaxation Space _______

Individual Study Space (I.E. Cubicles) _______

Classrooms _______

Please list any other thoughts or suggestions here:

____

____

____

____

____

A1: Faculty Survey

Renovation of the Kaven Hall Attic Faculty Survey

As part of our MQP, we are researching the type(s) of space needed by the Civil Engineering Department. Your help is greatly appreciated. Please rank the following spaces from 1 to 7, 1 being the most needed, 7 being the least needed.

Tech Suites _______

Conference Rooms _______

Lounge/Relaxation Space _______

Individual Study Space (I.E. Cubicles) _______

Classrooms _______

Professor Offices _______

T.A. Offices _______

Please list any other thoughts or suggestions here:

A2: Student Responses

STUDENTS	TECH SUITES	CONFERENCE ROOMS	LOUNGE SPACE	IND. STUDY SPACE	CLASSROOMS
1	1	2	5	4	3
2	3	2	5	1	4
3	1	2	4	3	5
4	1	2	5	3	4
5	1	5	2	3	4
6	1	2	5	3	4
7	4	2	1	3	5
8	3	4	2	1	5
9	1	2	5	4	3
10	1	4	3	2	5
11	1	3	5	2	4
12	2	3	5	4	1
13	3	2	5	4	1
14	1	3	2	5	4
15	1	3	4	2	5
16	1	3	2	5	4
17	2	4	5	3	1
18	4	5	1	2	3
19	3	4	2	5	1
20	1	3	5	2	4
21	1	2	3	4	5
22	1	5	4	3	2
23	1	3	2	4	5
24	1	3	2	5	4
25	1	3	2	5	4
26	1	3	5	4	2
27	2	1	5	3	4
28	2	1	3	5	4
29	1	3	4	2	5
30	1	3	2	4	5
31	3	2	4	5	1
32	3	2	4	5	1
33	2	3	4	5	1
34	1	3	2	5	4
35	3	5	1	4	2
36	1	5	4	2	3
37	1	3	4	5	1
38	1	2	5	4	3
39	1	3	2	5	4

40		1	4	5	3	2
41		5	4	2	3	1
42		2	1	3	5	4
43		2	3	4	5	1
	1	26	3	3	2	10
	2	7	12	12	7	4
	3	7	17	4	10	5
	4	2	6	10	10	15
	5	1	5	14	14	9
AVERAGE:		1.72	2.95	3.47	3.63	3.2

A3: Faculty Responses

FACULTY	TECH SUITES	CONFERENCE ROOMS	LOUNGE SPACE	IND. SPACE	CLASSROOMS	PROF. OFFICES	T.A. OFFICES
1	?	3	5	2	2	2	2
2	2		3	1		4	
3		3	1	2			

Appendix B: Structural Analysis and Design

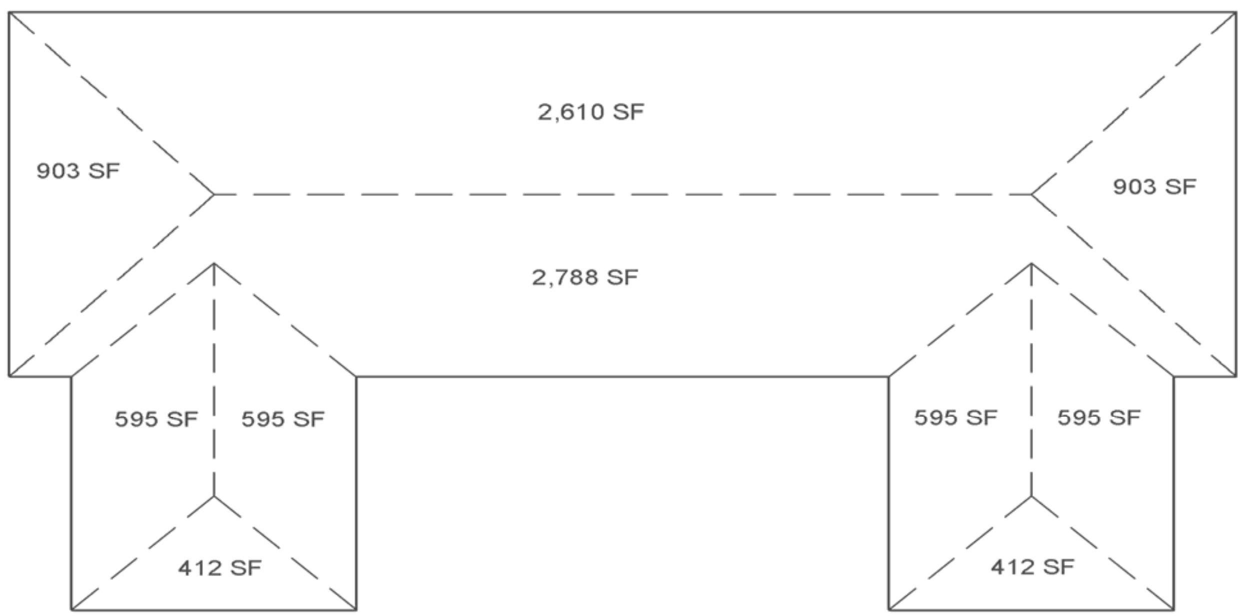
B1: Load Calculations

Roof Load Calculations

Roof Materials:

½” Slate Shingles:	20psf	(Appendix A-Wood Structures)
1” Lumber Sheathing:	2.5psf	
¾” Plywood:	+2.25psf	
Total Loading:	24.75psf	

Roof Area:



3,610.3sf
2,787.8sf
902.9sf x 2
594.9sf x 4
+411.25sf x 2
11,406 square feet of roof

Weight of Roof: (24.75psf x 11,406sf) = 282,298.5lbs = 282 kips

Concrete Slab Load Calculations

Dead Load of Slab:	60 psf (Appendix Reinforced Concrete)
Dead Load of Floor Finish and Lighting:	15 psf
Total Dead Load:	75 psf
Live Load of Institutional Building:	100 psf

Factored Loading:

1.2DL + 1.6LL=1.2(75psf) + 1.6(100psf) = 340 psf

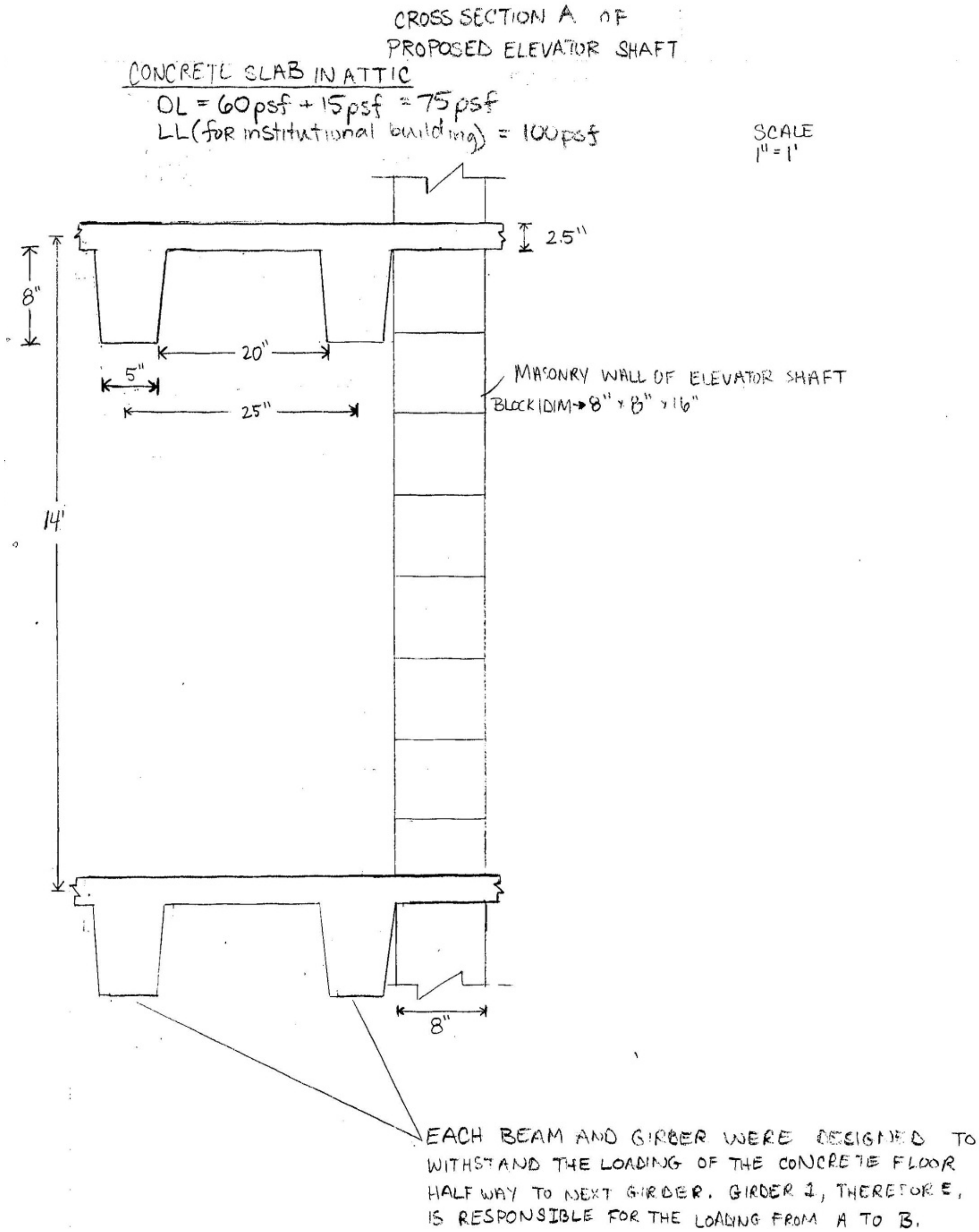
Stair Load Calculations

Dead Load:	200 psf
Live Load:	100 psf

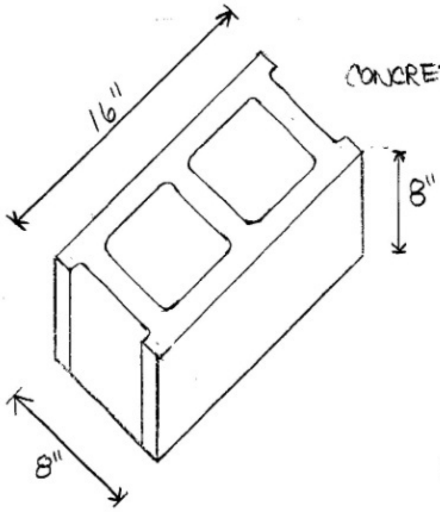
Factored Loading:

1.2DL + 1.6LL=1.2(200 psf) + 1.6(100 psf) = 400 psf

B2: Elevator Design



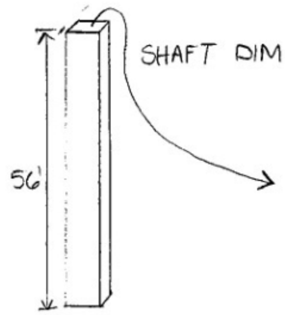
SINCE THERE ARE 20" BETWEEN GIRDERS, EACH GIRDER IS RESPONSIBLE FOR 10" ON EITHER SIDE. ALSO, SINCE THE MASONRY WALL IS 8" THICK, IT WILL NOT BE REQUIRED TO BEAR ANY LOAD OF THE FLOOR SLAB.



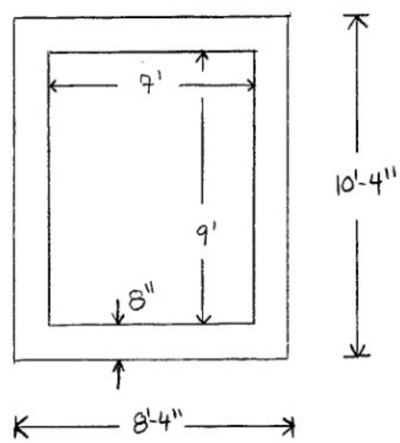
CONCRETE BLOCK DIM → 8" × 8" × 16" = 1024 in² → VOLUME

CONCRETE BLOCK WEIGHT = 32 lbs/block

COMPRESSION STRENGTH = 15000 psi (CHING, 2008)



SHAFT DIM → 56' × 8'-4" × 10'-4" = 4818.74 ft³



TOP SECTIONAL AREA =
(8'-4" + 9') 8" =

(100" + 108") 8" =

800 in² + 864 in² = 1664 in² × 2 = 3328 in²
↑ FOR 2 OF EACH WALL

HEIGHT OF SHAFT = 56' = 672"
HEIGHT OF BLOCK = 8"

$\frac{672"}{8"}$ = 84 BLOCKS ↕

LENGTH OF SHAFT = 9' = 108"
LENGTH OF BRICK = 16"

$\frac{108"}{16"}$ = 6.75 BLOCKS ↗

WIDTH OF SHAFT = 8'-4" = 100"
LENGTH OF BRICK = 16"

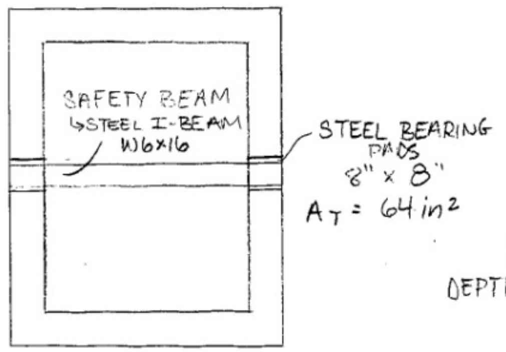
$\frac{100"}{16"}$ = 6.25 BLOCKS ⟷

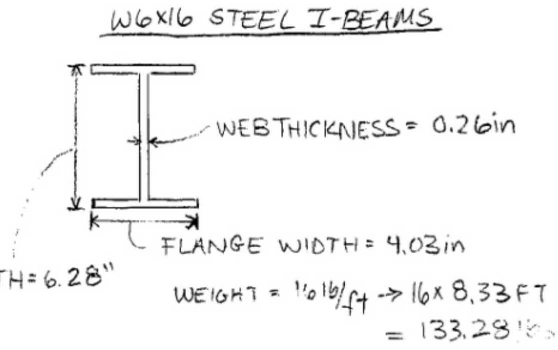
TOTAL AMOUNT OF BLOCKS NEEDED FOR SHAFT:
2(6.25 · 84) = 1050 BLOCKS
2(6.75 · 84) = 1134 BLOCKS
1050 + 1134 = 2184 BLOCKS

2184 BLOCKS × 32 lb/block = 69,888 lbs = TOTAL WEIGHT OF SHAFT

TOTAL WEIGHT OF ELEVATOR CAR WITH MAX OCCUPANCY: 4,000 lbs

TWO STEEL BEARING PADS TO BE PLACED ON TOP OF SHAFT TO DISPERSE THE LOAD FROM SAFETY BEAM PLUS ELEVATOR CAR WITH MAX OCCUPANCY IN CASE OF FAILURE.



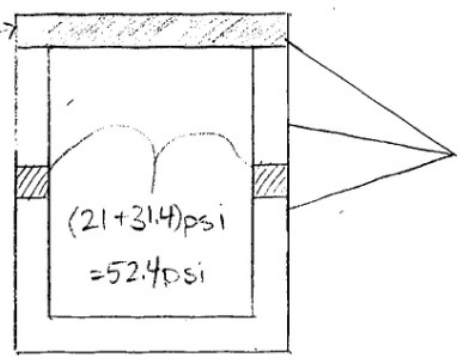


$4{,}000\text{lbs} + 133\text{ lbs} = 4133\text{lbs} \div 2 = 2007\text{ lbs/steel pad}$

$\frac{2007\text{lbs}}{64\text{ in}^2} = 31.4\text{psi}$ per pad (BENDING PRESSURE)

TOTAL LOADING OF MASONRY WALL + SAFETY BEAM PER UNIT AREA =

$\frac{69{,}888\text{ lbs}}{3328\text{ in}^2} = 21\text{psi}$



21psi

52.4psi < 1500psi ✓

LOAD FROM EACH CONCRETE FLOOR SLAB ⇒ DL = 75psf
LIVE LOAD FOR INSTITUTIONAL BUILDING → 100psf
AREA ON EACH FLOOR NEEDED TO BE SUPPORTED = 26.4 FT²

FACTORED LOADING = $1.2DL + 1.6LL \rightarrow (1.2)(3 \times 75) + (1.6)(100) = 430\text{psf}$ (3 SLABS)

$430 \frac{\text{lb}}{\text{ft}^2} \times 26.4\text{ ft}^2 = 11{,}352\text{lb}$

AREA OF WALL TO SUPPORT SLAB → $8'\text{-}4" \times 8" = 800\text{in}^2$

$\frac{11352\text{lb}}{800\text{ in}^2} = 14.19\text{ psi}$

MAX POSSIBLE LOADING ON ANY SECTION OF MASONRY WALL:

$(31.4 + 21 + 14.2)\text{psi} = \boxed{66.59\text{psi}} < 1500\text{psi}$ ✓ → (CHING, 2008)

B3: Stair Design Calculations

HSS 12 × 2 × 1/4

$I = 86.9 \text{ in}^4$

$C = 4.64 \text{ in}$

$$\frac{1}{8} \omega_u L^2 \leq \frac{\phi \sigma I}{C}$$

$$\omega_u \leq \frac{\phi \sigma I 8}{C L^2}$$

$$\omega_u \leq \frac{(.9)(50\text{ksi})(86.9\text{ in}^4)(8)}{(4.64\text{in})(170\text{in})^2}$$

$$\omega_u \leq .1123 \text{ k/in} = 1.347 \text{ k/ft} = 1347 \text{ lb/ft}$$

$$\omega_u = 1.2D + 1.6L$$

$$1347 \text{ lb/ft} = 1.2(120.6) + 1.6 L_{max}$$

$$\boxed{L_{max} = 750 \text{ lb/ft}}$$

$$\boxed{LL_{max} = (2)(750) = 1500 \text{ lb/ft}}$$

PL 1/2 × 12 × 14'2

$$I = \frac{1}{12} bh^3 = \left(\frac{1}{12}\right)\left(\frac{1}{2}\right)(12)^3 = 72 \text{ in}^4$$

$$c = \frac{h}{2} = \frac{12}{2} = 6 \text{ in}$$

$$\omega_u \leq \frac{\phi \sigma I 8}{c L^2}$$

$$\omega_u \leq \frac{.9(50)(72)(8)}{(6)(170)^2}$$

$$\omega_u \leq .1495 \text{ k/in} = 1794 \text{ lb/ft}$$

$$\omega_u = 1.2D + 1.6L$$

$$1794 = 1.2(120.6) + 1.6 L_{max}$$

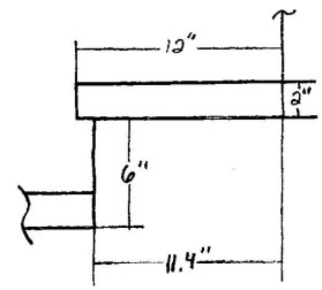
$$\boxed{L_{max} = 1030 \text{ lb/ft}}$$

$V_{steel} = [(4)(1/2)(14'2'')(12) + (2)(1/2)(14'2)(12) + [(12)(17.4) + 6](1/2)(4 \cdot 12)$
$= 7782.8\ in^3$
$= 4.5\ ft^3$
$W_{steel} = (4.5\ cf)(490\ pcf) = 2205\ lbs.$

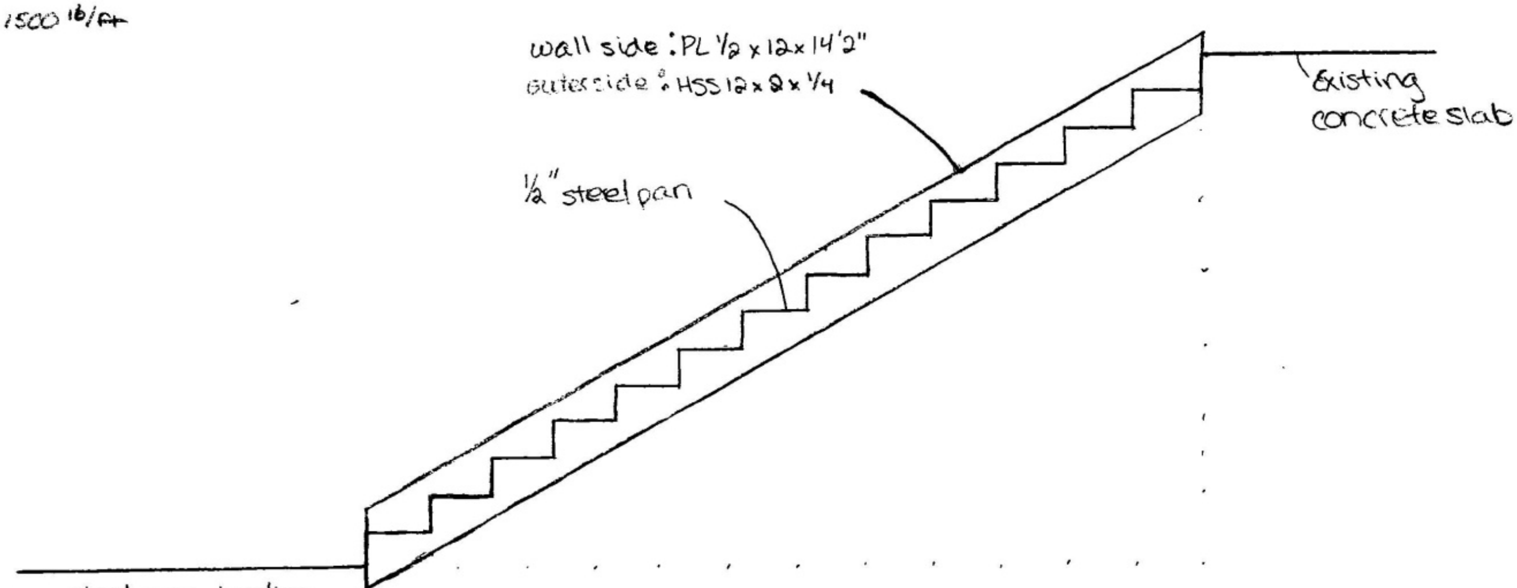
$V_{concrete} = (12)(2)(48)(13) = 14976\ in^3 = 8.67\ cf$
$W_{concrete} = (8.67)(140\ pcf) = 1213.3\ lbs$

$D.L. = (2205 + 1214) \div 14'2'' = 241.3\ lb/ft$
$1/2\ DL = 120.6\ lb/ft$

$LL_{max} = 1500\ lb/ft$



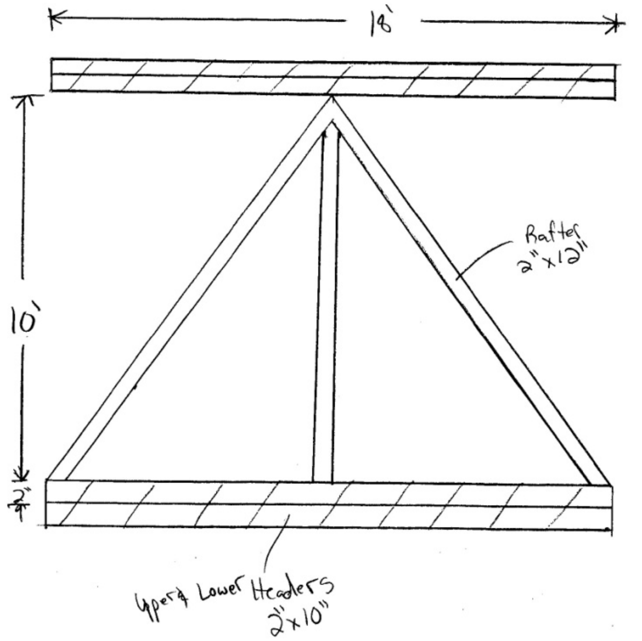
Step Detail

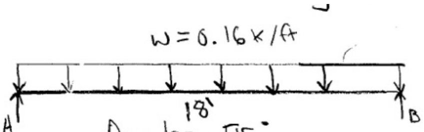


Stair cross section

Scale: 1 block = 5mm : 6"

B4: Dormer Design





(Appendix B – Wood Structures)
Live Load = 100 psf
Snow Load = 35 psf
Dead Load (Roof) = 24.75 psf

Try Douglas - Fir:

$M_u = \frac{wL^2}{8} = \frac{(0.16\ k/ft)(18^2)}{8} = 6.48$ ft-lb $= 77.76$ in-Kip

$F'b = F_b\,(C_D)(C_M)(C_t)(C_L)(C_F)(C_{fu})(C_i)$ (Wood Structures)
$F'b = (1000)(1.30)(1.0)(1.0)(1.0)(1.15)(1.35)(1.0)$
$F'b = 2018$ psi

Req'd $S = \frac{M}{F_b} = \frac{77760\ in\text{-}lb}{2018\ psi} = 38.5\ in^3$

Try 2"x10" No.1 Douglas Fir (evaluate as 4"x10")
$S = 49.9\ in^3$ (NDS supplement)

$S = 49.9\ in^3 > $ Req'd $S = 38.5\ in^3$ OK

$f_b = \frac{M}{S} = \frac{77760\ in\text{-}lb}{49.9\ in^3} = 1558.32$ psi

$F'b = 2018$ psi > 1558.32 psi

∴ Bending OK

$A = 32.375\ in^2$ (Table 4A NDS supplement)

$f_v = \frac{1.5V}{A} = \frac{1.5(720)}{32.375\ in^2} = 5.56 = 66.72$ psi

$F_v = 180$ psi (Table 4A NDS supplement)
$F'v = F_v(C_D)(C_m)(C_t)(C_i) = 180(1.15)(1.0)(1.0)(1.0) = 207$ psi

$f_v = 66.72$ psi $< F'v = 207$ psi
∴ Shear OK.

$E' = E(C_M)(C_t)(C_i) = 1{,}700{,}000(1.0)(1.0)(1.0) = 1{,}700{,}000$ psi

$\Delta_L = \frac{5 w_L L^4}{384 E' I} = \frac{5(0.16)(18^4)(1728)}{384(1{,}700{,}000)(20.8)} = 0.012$ in.

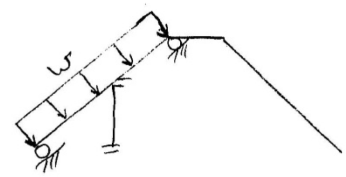
Allow $\Delta_L = \frac{L}{240} = \frac{18 \times 10}{240} = 0.75$ in > 0.012 in.

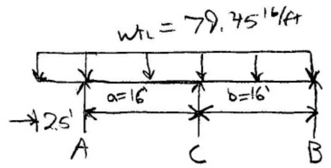
∴ Deflection OK

Use 2"x10" No. 1 DF-L MC ≤ 19%

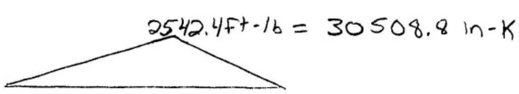
B5: Roof Joist Analysis

Live Load = 100 psf
Snow Load = 35 psf
2" x 12" = 2.9 psf (Appendix A – Wood Structures)





$W_D = 24.75 \times 1.33 = 32.9$
$W_L = 35 \times 1.33 = 46.55$
$w_{TL} = 79.45$ lb/ft



$F_b = 1000$ psi (Table 4A NDS Supplement)
E = 1,700 ksi (" ")

$F'b = F_b (C_D)(C_M)(C_t)(C_L)(C_F)(C_r)(C_i)$ (Wood Structures)
$F'b = 1000(1.15)(1.0)(1.0)(1.0)(1.2)(1.0)(1.0)$
$F'b = 1380$ psi

$\text{Req'd } S = \frac{M}{F'b} = \frac{30508.8}{1380\text{psi}} = 22.1 \text{ in}^3$

Try 2" x 12" $S = 31.64 \text{ in}^3 > 22.1 \text{ in}^3$ OK

$f_b = \frac{M}{S} = \frac{30508.8}{31.64} = 964$ psi

$F'b = 1380$ psi > 964 psi

∴ Bending OK

$$f_v = \frac{1.5V}{A} = \frac{1.5(120)}{16.14} = 11.15 \text{ psi}$$

$$f'_v = F_v(C_D)(C_m)(C_t)(C_i)$$
$$f'_v = 180(1.15)(1.0)(1.0)(1.0) = 207 \text{psi} > 11.15$$

$\therefore$ shear OK

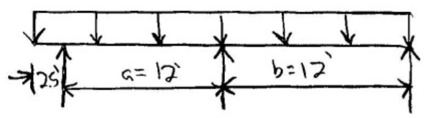
$$E' = E(C_m)(C_t)(C_i) = 1,700,000(1.0)(1.0)(1.0) = 1,700,000 \text{ psi}$$

$$\Delta_L = \frac{5w_L L^4}{384E'I} = \frac{5(48.55)(16)^4(1728 \text{ in}^3/\text{ft}^3)}{384(1,700,000)(20.8)} = 1.43 \text{ in}$$

Use 2x12 No. 1 DF-L
MC ≤ 19 percent

Snow Load = 35psf

2"x12" = 2.9psf (Appendix A - Wood Structures Text)



$F_b = 1000$ psi (Table 4A NDS Supplement)

$E = 1{,}700$ ksi

$F'b = F_b (C_D)(C_m)(C_t)(C_L)(C_F)(C_r)(C_i)$ (Wood Structures)

$F'b = 1000(1.15)(1.0)(1.0)(1.0)(1.0)(1.2)(1.0)(1.0)$

$F'b = 1380$ psi

$$\text{Req'd } S = \frac{M}{F'b} = \frac{30508.8}{1380\text{psi}}\ 22.1\text{in}^3$$

$S = 31.64\text{in}^3 > 22.1\text{in}^3$ OK

$$f_b = \frac{M}{S} = \frac{30508.8}{31.64} = 964\text{ psi}$$

$F'b = 1380\text{ psi} > 964\text{ psi}$

∴ Bending OK

$$f_v = \frac{1.5V}{A} = \frac{1.5(120)}{16.14} = 11.15\text{psi}$$

$f'v = F_v (C_D)(C_m)(C_t)(C_i)$

$f'v = 180(1.15)(1.0)(1.0)(1.0) = 207\text{psi} > 11.15\text{psi}$

∴ Shear OK

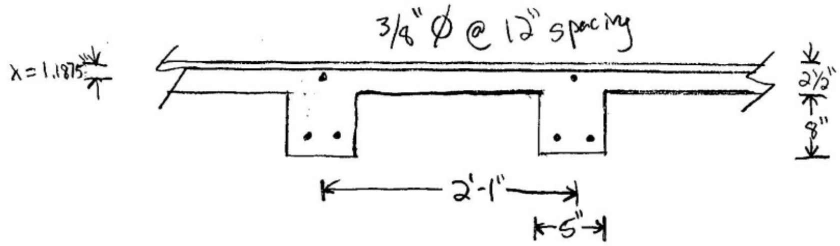
$E' = E(C_m)(C_t)(C_i) = 1{,}700{,}000(1.0)(1.0)(1.0) = 1{,}700{,}000\text{psi}$

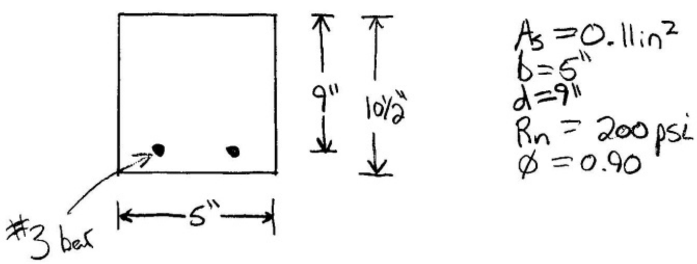
$$\Delta_L = \frac{5w_L L^4}{384E'I} = \frac{5(46.55)(12^4)(1728\text{in}^3/\text{ft}^3)}{384(1{,}700{,}000)\ 120.8)} = 0.614\text{ in.}$$

Use 2x12 No. 1 DF-L

MC ≤ 19 percent

B6: Concrete Slab Design





Dead Load = 75 psf (Appendices - Reinforced Concrete)

Live Load = 100 psf

$M_n = R_n b d^2 = (200)(5)(9^2) = 81{,}000\ in \cdot K = 6750\ ft \cdot K$

$\phi M_n = 0.9(6750) = 6075\ K \cdot ft$

$M_u = \frac{w_u L^2}{8}$ $w_u = 1.2D + 1.6L = 1.2(75 psf) + 1.6(100 psf)$

$w_u = 250 psf = 0.50\ K/ft$

$M_u = \frac{(0.50 K/ft)(720 in)^2}{8} = 2700\ K \cdot ft$

$M_u = 2700\ K \cdot ft \leq \phi M_n = 6075\ K \cdot ft$

* Loading OK

Use concrete strength, $f'_c = 3000 psi$ and a yeild strength of $f_y = 40{,}000 psi$. The slab will be sustainable under a total load of 250 psf.

Appendix C: Heat Loss

C1: Heat Loss Calculations

NEW ROOF COMPOSITION

Outside Air Film	0.17
1/2" Slate	0.05
3/4" plywood	0.94
vapor seal	0.1
inside air Film	0.62
Framing	+ 0.37
1/2" Gypsum Board	0.5
	2.75
3" Insulation (R-8/in)	+ 24
	R-26.75 → Total R-Value for Roof

(CMR 1305.1)

$$U\text{-Value} = \frac{1}{R\text{-Value}} = 0.0374$$

AREAS

5 SKYLIGHTS @ 5'x5'4" ea. → 26.67 SF ea → x5 = 133.33 SF

2 WINDOWS @ 8'x4'6" ea → 36 SF ea → x2 = 72 SF

1 WINDOW @ 4'x4'6" → 18 SF → = 18 SF

ROOF + DORMERS − (WINDOWS + SKYLIGHTS) → = 11,839.15 SF

TOTAL HEAT LOSS EQUATION:

$$q_x = \Sigma(U \times Area) \times \text{Temp. Diff}$$

$(T_{inside} - T_{outside})$

$(75° - 20°)$

[Fundamentals of Heat and Mass Transfer, 2007, Incropera/DeWitt/Bergman/Lavine. Chap 3 EQ 3.17]

MATERIAL	U-VALUE		AREA (SF)		(U × Area)
Skylight (5)	1.9	×	133.33	→	253.33
Dormer Window (2)	1.1	×	72	→	79.2
Dormer Window (1)	1.1	×	18	→	19.8
Roof	0.0374	×	11,839.15	→	442.56

$\Sigma(U \times Area) = 794.915$

$\Sigma(U \times Area) \approx 795$

$q_x = (795)(55°) = 43{,}725$ BTU/hr

− 22,002 BTU/hr (CODE HEAT LOSS)

HVAC System Needs to Produce ⟹ **21,723 BTU/hr**

C2: Heat Loss Chart

Area (ft^2)	Openings	Opening Area (ft^2)	Net Area (ft^2)	U-value	Code U-value	ΔT	Heat Loss(Btu/hr)	Code Heat Loss(Btu/hr)	Btuh Needed(Btu/hr)
11, 406	Chimney	38.5	11, 364	0.43	0.033	55	262197	19901	242297
	Vents	4							
Area (ft^2)	Openings	Opening Area (ft^2)	Net Area (ft^2)	U-value	Code U-value	ΔT	Heat Loss(Btu/hr)	Code Heat Loss(Btu/hr)	Btuh Needed(Btu/hr)
12, 014	Chimney	38.5	38.5	0.13	0.033	55	43, 725	22, 002	21, 723
	Skylights (5@ 5'x5'-4"	133.33	666.65	1.9					
	Window (2@8'x4'6")	72	144	1.1					
	Window (1@4'x4'6")	18	18	1.1					