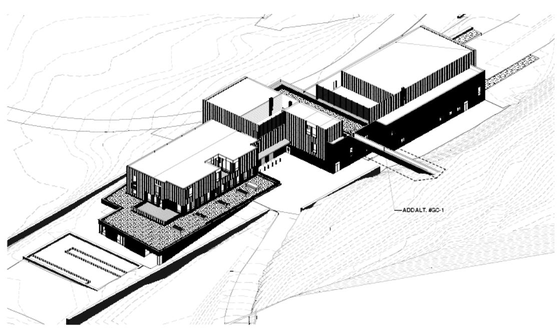
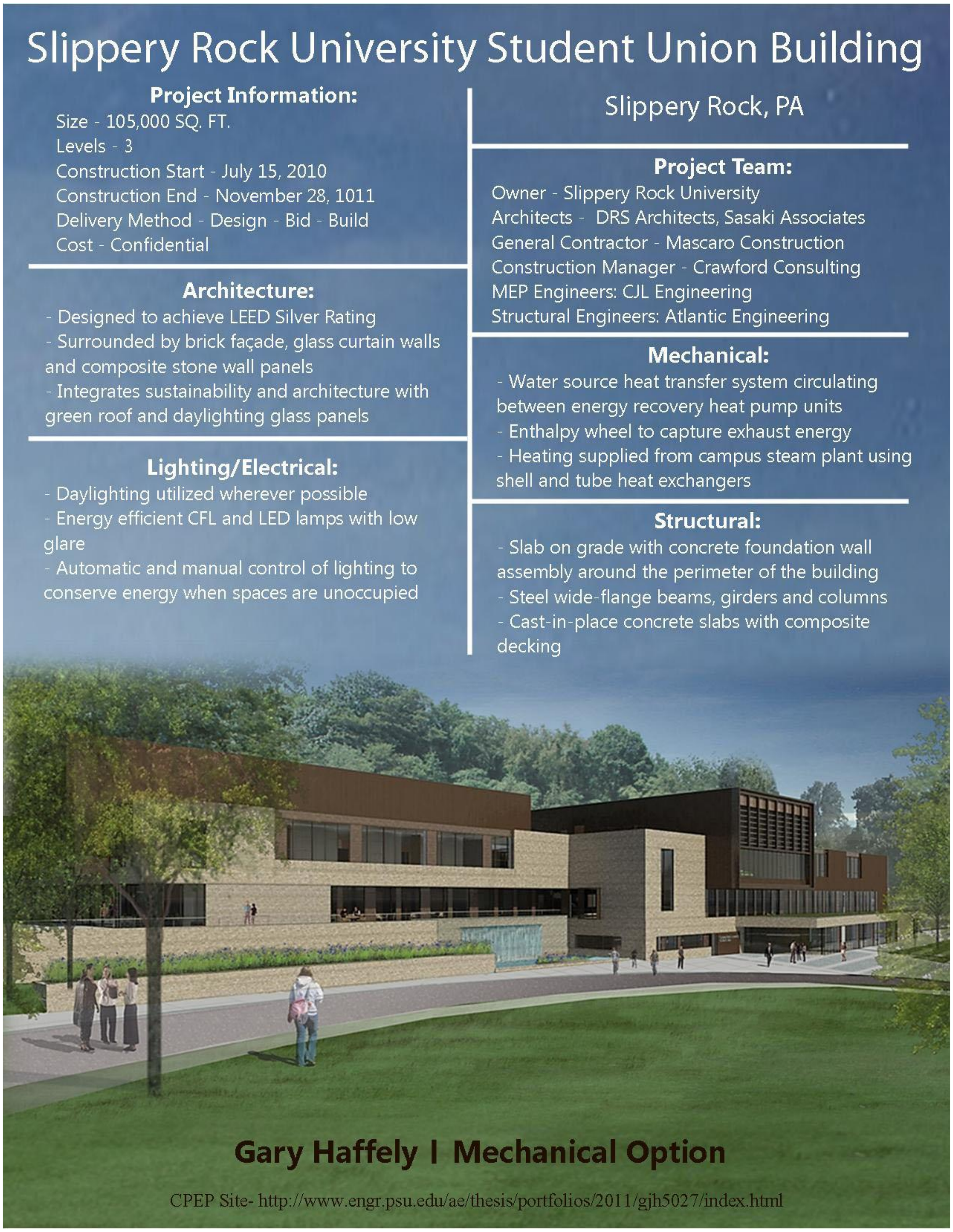
# Final Report

Redesign Project

Slippery Rock University Student Union

Slippery Rock, PA




Slippery Rock University Student Union Building
Project Information:
Size - 105,000 SQ. FT.
Levels - 3
Construction Start - July 15, 2010
Construction End - November 28, 1011
Delivery Method - Design - Bid - Build
Cost - Confidential
Slippery Rock, PA
Project Team:
Owner - Slippery Rock University
Architects - DRS Architects, Sasaki Associates
General Contractor - Mascaro Construction
Construction Manager - Crawford Consulting
MEP Engineers: CJL Engineering
Structural Engineers: Atlantic Engineering
Architecture:
- Designed to achieve LEED Silver Rating
- Surrounded by brick façade, glass curtain walls and composite stone wall panels
- Integrates sustainability and architecture with green roof and daylighting glass panels
Mechanical:
- Water source heat transfer system circulating between energy recovery heat pump units
- Enthalpy wheel to capture exhaust energy
- Heating supplied from campus steam plant using shell and tube heat exchangers
Lighting/Electrical:
- Daylighting utilized wherever possible
- Energy efficient CFL and LED lamps with low glare
- Automatic and manual control of lighting to conserve energy when spaces are unoccupied
Structural:
- Slab on grade with concrete foundation wall assembly around the perimeter of the building
- Steel wide-flange beams, girders and columns
- Cast-in-place concrete slabs with composite decking
Gary Haffely I Mechanical Option
CPEP Site- http://www.engr.psu.edu/ae/thesis/portfolios/2011/gjh5027/index.html

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# 1.0 Executive Summary

The Slippery Rock University Student Union was designed by the architects and engineers with the intent to deliver a comfortable environment inside and outside of the building in hopes of creating a central gathering place of the campus. While occupant comfort was a major design condition, building performance and energy conservation was equally as important in striving to achieve LEED Silver Certification. In the following report, the existing mechanical design will be researched, evaluated, and redesigned.

The existing mechanical design is comprised of five rooftop air handling units with energy recovery that supply the majority of the occupied spaces with the proper heating, cooling and ventilation. The electrical and IT rooms are cooled by a separate ductless split system due to the excessive internal heat loads caused by the equipment. Three additional make-up air units are located on the roof supplying the kitchen with ventilation air. The energy recovery units utilize a water heat transfer system to exchange heat between the units to further decrease wasted energy within the system and are also equipped with variable frequency drives.

The campus steam plant provides the SRU Student Union with steam to heat the water used in the hot water heating system for the VAV boxes with hot water heating coils. The cooling is provided through the water source heat transfer system that is tied into two closed circuit coolers located on the roof.

In the report, a different method of providing the building with heating, cooling and ventilation is explored. The topic of redesign is to change three of the existing air handlers with energy recovery to a dedicated outdoor air system with active chilled beams. The systems overall performance created an annual savings of $5,985.71 with an additional first cost of $41,934.88 for a simple payback period of 7 years.

An additional system was also added to the mechanical design. The use of an evacuated tube system for solar hot water was designed and evaluated. With the combination of the cost savings from the existing portion of the green roof and the government incentives, the new system has a net savings of $15,336.50. However, without the incentives, the system does not appear to be economically feasible.

The structural implications of replacing composite steel deck with precast hollowcore planks were also evaluated. The overall consensus of the structural analysis seems that the precast planks could be used however coordination and planning could potentially become an issue. The first cost analysis of the system saved $83,287.75 and also accelerated the construction time of the structure.

# 2.0 Project Information

## 2.1 Design Goals

The Slippery Rock University Student Union construction is currently underway with building completion estimated to be in late November of 2011. The 105,000 square foot building will serve many different types of activities and will house spaces such as a bookstore, kitchen, cafeteria, ballroom, theater, student lounges, retail shops along with numerous offices and conference rooms. The building is currently predicted to achieve a LEED Silver Rating.

The SRU Student Union will be used by primarily students and faculty year round. The ground floor will contain the large bookstore and house all of the interior mechanical equipment. The second floor has spaces available to hold club meetings and conferences for the student organizations within the university. The faculty will also be occupying the building, with a portion on the second floor of the building dedicated into individual offices. The remaining west side of the floor will contain a full kitchen and dining commons. A ballroom and theater room is located on the floor directly above the kitchen and dining area on the third floor. The east side of the third floor will house the remaining meeting rooms.

The exterior landscape of the building will allow the students and faculty to have areas where outdoor seating is available. The SRU Student Union will hope to be the central meeting and gathering place of the Slippery Rock University Campus.

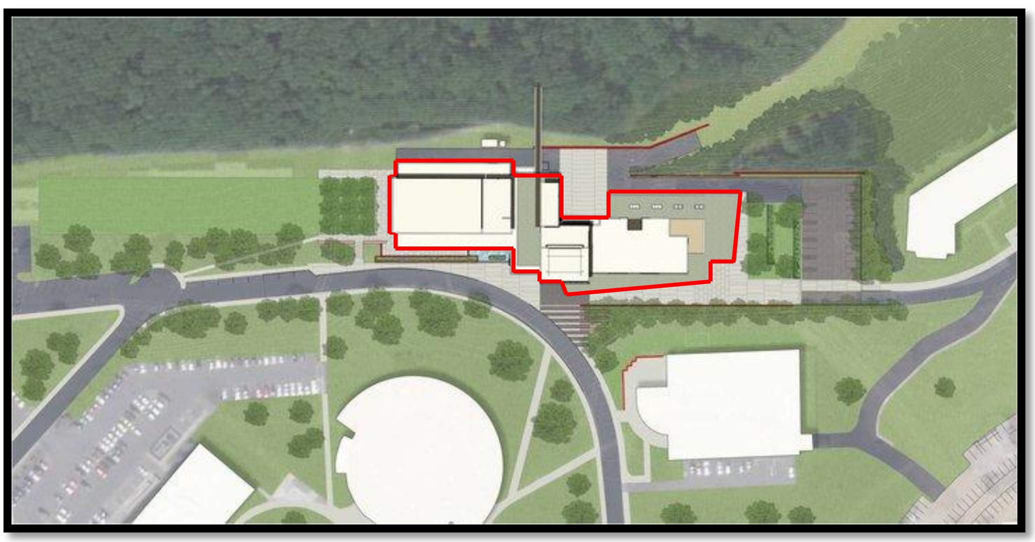


**Figure 1 – Campus Site Plan**

## 2.2 Building Information

- **Building Name:** Slippery Rock University Student Union
- **Location and site:** Slippery Rock, Pennsylvania
- **Occupancy type:** Student Center
- **Size:** 105,000 SF
- **Number of Stories:** 3 Floors
- **Cost Information:** Confidential
- **Project Delivery Method:** Design-Bid-Build

## 2.3 Project Team

- **Owner:** Slippery Rock University
- **General Contractor:** Mascaro Construction
- **Architects:** DRS Architects
- **MEP Engineers:** CJL Engineering
- **Structural Engineers:** Atlantic Engineering Services
- **HVAC Contractor:** Renick Brothers
- **Electrical Contractor:** Yates Contracting
- **Plumbing Contractor:** Vrabel Plumbing

# 3.0 Existing Conditions and Building Overview

## 3.1 Architecture/Building Enclosure

The building is enclosed by a brick façade, glass curtain walls and composite stone wall panels. It is designed to integrate sustainability with the architecture and surroundings to invoke a natural feeling when inside and outside the building. The large glass panels allow this sensation to occur by the mass amount of natural daylighting that is present in every applicable space. The building enclosure consists of brick and prefabricated curtain wall panels. Large glass curtain walls are also present on a large portion of the southern façade.

## 3.2 Sustainability

The Slippery Rock University Student Union Building strives to achieve LEED Silver rating. Through various active and passive systems, the building will have the capacity to lower its energy and natural resource consumption. By incorporating natural daylighting, the building is able to conserve energy on both lighting the spaces along with cutting out the additional lighting heat load. This was possible by close planning and coordination between the design engineers and architects. When daylighting is unavailable, efficient LED and CFL luminaire configurations are used to further reduce energy consumption. The heating and cooling will be provided through a water source heat transfer system circulating throughout the five separate energy recovery units. Due to the nature of the building, simultaneous heating and cooling will occur allowing heat recovery between different zones to be utilized. The air handlers are also equipped with energy recovery wheels and VAVs to reduce energy usage at low loads.

## 3.3 Mechanical

The mechanical system is comprised of five energy recovery units that are used to serve ventilation air to all the occupied spaces in the building. These energy recovery units provide the building with the minimum required ventilation air. They use energy wheels to transfer exhaust energy to the incoming outdoor air. Due to the nature of the building, simultaneous heating and cooling occurs year round so a hot water heat transfer system is utilized to avoid auxiliary energy use. These units are also equipped with variable volume drives to conserve energy output when heating and cooling loads are low. There are three 24,000 cfm ERU’s and two 16,000 cfm ERU’s, which are sized such that they can supply the entire building with proper ventilation and can meet the peak heating and cooling loads.

The building also uses three make-up air units to provide proper ventilation in the kitchen area, where large exhaust fans are located. The make-up air units also provide the space with 100 percent outdoor air. Additionally, there is a ductless split-system which serves the IT and electrical rooms, which generate a lot of heat due to all of the electrical equipment.

## 3.4 Construction

The building contract was design-bid-build, however, it was not awarded to the lowest bidder. The Mascaro Construction Company was awarded the contract because of their Minority Business Enterprise and Women's Business Enterprise (MBE/WBE) participation. The building construction uses deep foundations due to the instability in the surrounding soil. Caisson piers are used, sized as large as 72 inches in diameter and 22 feet deep. The dirt is removed then a hollow form is placed in the hole. The rebar is dropped into place then filled with concrete. These are used to prevent vertical movement in the building which causes cracks as differential soil settling occurs. Specialty contractors will be used for construction of the custom fireplace, green roof, and a custom designed fountain.

## 3.5 Structural

The foundation consists of caisson piers up to 22 feet deep with a 16 inch slab on grade. The north facing walls are concrete load bearing to support the green roof. The main structure of the building contains a steel column and beam system with composite steel deck for the floor system. The columns typically run 16 feet on center north to south with small variations and roughly 24 feet on center east to west also with a few bay variations to accommodate the ballroom and theater. Web joists 16 inches on center run east to west support the theater.

## 3.6 Electrical

The 15kV electrical utility line comes in to a new electrical manhole from the southern side of the building. It then runs beneath the building to the northern side where there is a concrete electrical equipment pad to house a generator and a transformer. It contains a 1500 kVA transformer with 15kV primary stepped down to a 480/277 V, 3 Phase, 4W secondary along with a 200 kW generator in a weatherproof enclosure. Both connect to the main electrical room located on the first floor which is then used to supply the building with power.

## 3.7 Lighting

The building incorporates natural daylighting along most of the southern façade and wherever possible using shades to avoid excessive glare. Automatic controls with manual override are used to allow for occupants to control the amount and intensity of light in each space. The system is equipped with dimmers to allow less energy consumption when lighting load is low. The controls can also be programmed such that they change based on the time of day and hours of occupancy. CFLs and LEDs are used rather than conventional incandescent lights to conserve energy. The fixtures are high efficiency with high power factor electronic ballasts.

## 3.8 Fire Protection

The building is equipped with ADA compliant audio and visual alarms where necessary. The building has motorized doors connected to the fire alarm system and will open upon a signal from the smoke evacuation system. When the smoke evacuation system is implemented, a 75,000 cfm exhaust fan located in the atrium will turn on. The doors and windows in the atrium will simultaneously open and allow for the exhaust fan to pull air in and take out the smoke through the exhaust located on the roof.

## 3.9 Telecommunications

Dual 600 copper cable telecommunications and data lines run to an existing manhole. A new telecommunications line runs from the existing manhole into the eastern side of the building, where it ties into the electrical and IT room. The other existing line then runs into the western side of the building.

## 3.10 Transportation

The building can be accessed by its main means of entrance and egress located on the south west side of the building. Upon entering the atrium, a main and centralized staircase is present which enables you to access the floor above. There is another entrance on the south east side of the building. A staircase is located directly next to the vestibule that can also take the person to the remaining floors of the building. A third and final vestibule is located on the north east corner of the building giving access to the bookstore. On the roof of the building, a catwalk leading off the building is located as an added architectural feature along with providing another means of egress.

# 4.0 Existing Mechanical System Summary

## 4.1 Mechanical Design Objectives

The Slippery Rock University Student Union construction is currently underway with building completion estimated to be in late November of 2011. The building will serve many different types of activities and will house spaces such as a bookstore, kitchen, cafeteria, ballroom, theater, student lounges, and will also have various offices and conference rooms. With such a diverse environment, it is important to ensure comfort and wellbeing for the occupants throughout the long operation hours during all months of the year. In order to achieve this, careful planning was incorporated into the design to allow the occupants to have control of each space as much as possible.

In most cases, the building well exceeds minimum ventilation requirements set forth by ASHRAE Standard 62.1 and the minimum system efficiencies stated in ASHRAE Standard 90.1. The SRU Student Union is designed in order to obtain a LEED Silver Rating. To able to accomplish this achievement, energy recovery units with a hot water heat transfer system are used with auxiliary back up. Due to the different types of spaces in the building, simultaneous heating and cooling will be occurring, which allows for these units to run effectively.

Comfort is another major priority within the SRU Student Union. Each office, conference room, and lounge area in the building is equipped with a VAV box along with a thermostat so the individuals can have the space at their own comfort level. The nature of the building requires the larger spaces to be monitored by automatic controls to keep each space at a satisfactory temperature and humidity throughout operational hours. When outdoor conditions are suitable, natural ventilation can be utilized by operable windows where applicable. With careful consideration, the SRU Student Union will be a safe and comfortable environment for the occupants.

## 4.2 Energy Sources

The Slippery Rock Student Union will use several means of energy. The majority of the energy consumption will be in the form of electricity. The building will also use natural gas, and steam from the nearby campus steam plant. The following chart shows the energy costs per type.

**Table 1 – Electricity Demand and Consumption Rates**

| Electricity Rates | | |
|---|---|---|
| | 0-100 kW | >100 kW |
| Electric Demand ($/kW) | 7.04 | 6.05 |
| | 0-40,000 kWh | >40,000 kWh |
| Electric Consumption ($/kWh) | 0.05113 | 0.04615 |

**Table 2 – Natural Gas Rates**

| Natural Gas Consumption Rates | |
|---|---|
| Natural Gas ($/therm) | 1.16 |

**Table 3 – Steam Rates**

| Steam Consumption Rates | |
|---|---|
| Steam ($/therm) | 1.057 |

## 4.3 Indoor and Outdoor Design Conditions

The following design conditions were used based on the design conditions specific to the location. These design conditions are based on weather data supplied for Pittsburgh, PA because weather conditions for Slippery Rock, PA were unavailable.

**Table 4 – Outdoor Design Conditions**

| Outdoor Design Conditions | |
|---|---|
| Location | Pittsburgh, Pa |
| Summer Dry Bulb (°F) | 86 |
| Summer Wet Bulb (°F) | 71 |
| Winter Dry Bulb (°F) | 5 |
| Summer Clearness | 0.97 |
| Summer Ground Reflectance | 0.2 |
| Winter Clearness | 0.97 |
| Winter Ground Reflectance | 0.2 |
| Outdoor Carbon Dioxide Level | 400 |

**Table 5 – Indoor Temperature Settings**

| Indoor Temperatures Settings | |
|---|---|
| Cooling Dry Bulb (°F) | 74 |
| Heating Dry Bulb (°F) | 70 |
| Relatives Humidity % | 50 |
| Cooling Driftpoint (°F) | 80 |
| Heating Driftpoint (°F) | 64 |

## 4.4 Existing Building Zones and Equipment Summary

### 4.4.1 Existing Zones

The Slippery Rock University Student Union holds various types and varieties of functions throughout the building. The mechanical system is designed to supply these spaces effectively and as efficiently as possible by isolating each zone. The following list describes which air handler will provide air to the areas in the building. Figure 3 is a colored floor plan showing where these spaces are located.

- Zone 1: Heating only – This zone only requires the spaces to be heated. It contains the perimeter stairwells, mechanical rooms, and the entry vestibules.
- Zone 2: Energy Recovery Unit 1 – This unit will both heat in the winter and cool in the summer. Located on the roof, the energy recovery unit will provide air to the entrance lobby, café, UPS, cultural lounge, fireplace lounge, theatre, administrative offices, and surrounding corridors.
- Zone 3: Energy Recovery Unit 2 – This unit is also located on the roof and provides both heating and cooling. It serves the dining/cafeteria area, the kitchen support rooms, the servery, storage rooms, and the surrounding corridors.
- Zone 4: Energy Recovery Unit 3 – This energy recovery unit is located on the roof which provides ventilation to the student organization rooms, meeting rooms, and the circulation spaces throughout the area.
- Zone 5: Energy Recovery Unit 4 – This unit is located on the roof providing both heating and cooling. It serves the ballrooms and the pre-function and circulation space surrounding the ballrooms. It also provides ventilation to the supporting storage rooms.
- Zone 6: Energy Recovery Unit 5 – The final energy recovery unit is located indoors on the first floor. This unit serves the bookstore and its storage space and office space.
- Zone 7: Make-Up Air Units – Three make-up air units supply air to the kitchen hoods located on the second floor kitchen. These kitchen hoods exhaust large amounts of air so these units must bring in air in order to keep the space properly ventilated and conditioned.
- Zone 8: Ductless Split System Schedule – This system is used to combat the heat gain that is caused by the electrical and IT spaces located throughout the building. These rooms must be kept at a reasonable temperature in order to keep the equipment from being damaged.

| | |
|---|---|
| Zone 1 - Green: Heating Only | Zone 5 - Purple: ERU 4 |
| Zone 2 - Light Blue: ERU 1 | Zone 6 - Orange: ERU 5 |
| Zone 3 - Yellow: ERU 2 | Zone 7 - Pink: MUA |
| Zone 4 - Dark Blue: ERU 3 | Zone 8 - Red: Ductless Split System |

Figure 2 – Legend of Existing Zones

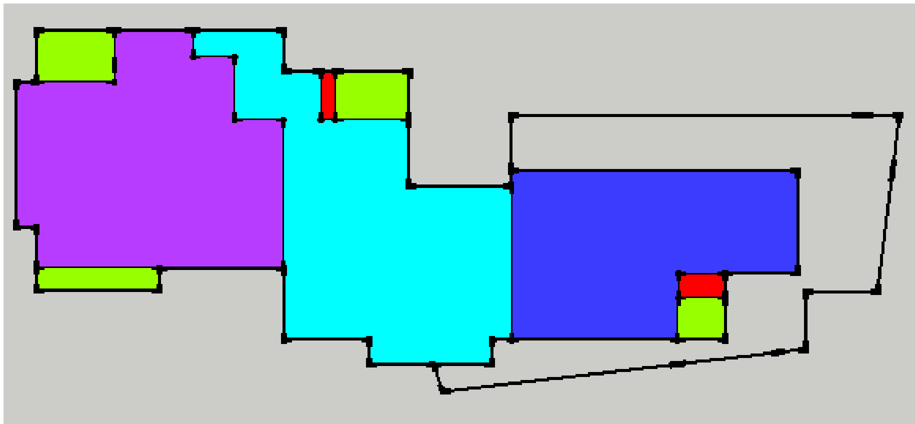


Figure 3 – Existing Third Floor Zone Layout

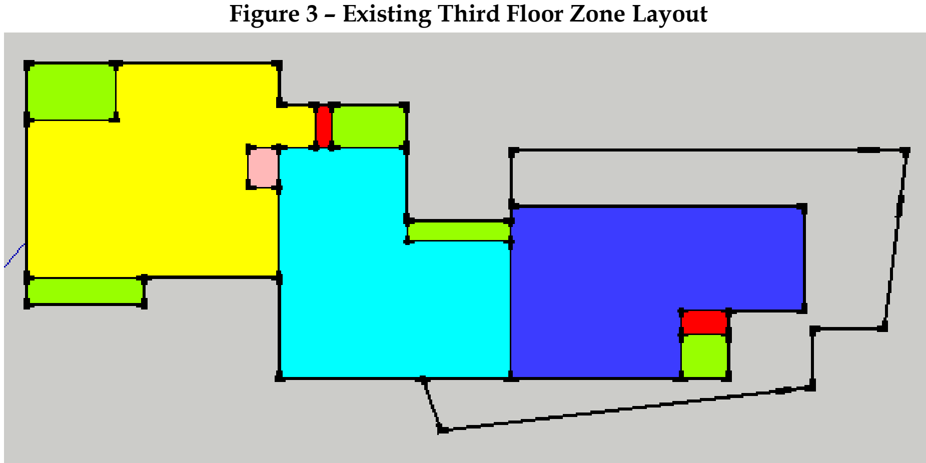


Figure 4 – Existing Second Floor Zone Layout

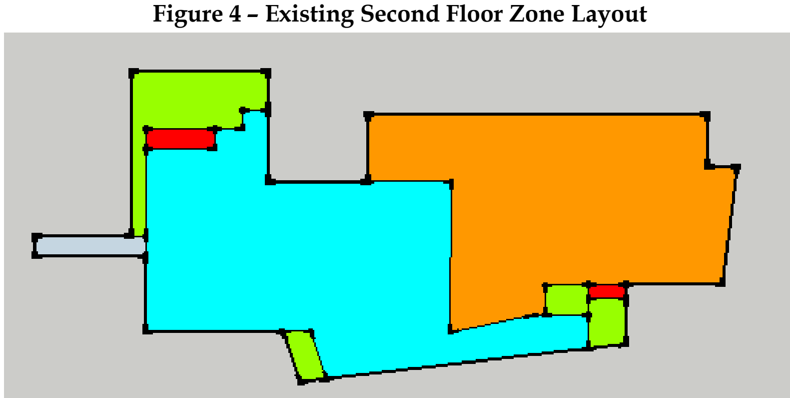


Figure 5 – Existing First Floor Zone Layout

### 4.4.2 Mechanical Equipment Summary

Most spaces in the building are heated, ventilated, and cooled by five separate energy recovery units with a hot water heat transfer loop between the units in the system using a 40% glycol-water mixture. Each energy recovery unit serves a different zone located in the building with remote control panels located in the mechanical room. Three make-up air handlers are used to provide 100 percent outdoor ventilation air to the kitchen area due to the mass amount of exhaust air from the kitchen hoods. The ductless split system is used to keep the IT rooms from overheating throughout the building. These rooms contain building servers and electrical equipment that put off large amounts of heat.

The building receives the steam from the university steam plant which is then taken to the heat exchangers where hot water is then pumped throughout the building used for heating in the hot water heat transfer system along with domestic hot water. The water used for cooling is provided by the campus chiller plant. It is then taken to heat exchangers to provide the building with an adequate cooling capacity throughout the year.

The building was designed to isolate the areas containing mechanical equipment. A large mechanical room is located on the northwest end on the first floor of the building. It houses heat exchangers, domestic hot water tanks, pumps, expansion tanks, various types of vavles, and piping. Another mechical room is located on the first floor located on the northern side of the building that contains an energy recovery unit that services the bookstore and surrounding support areas. The ductless split system evaporators are located in the IT rooms throughout the building. Each condesndsor serves three indoor evaporators. The remaining four energy recovery units, two cooling towers, three ductless split system condensors, three make-up air units, and exhaust fans are located on the rooftop.

## 4.5 System Evaluations and Schematics

### 4.5.1 Air Flow System

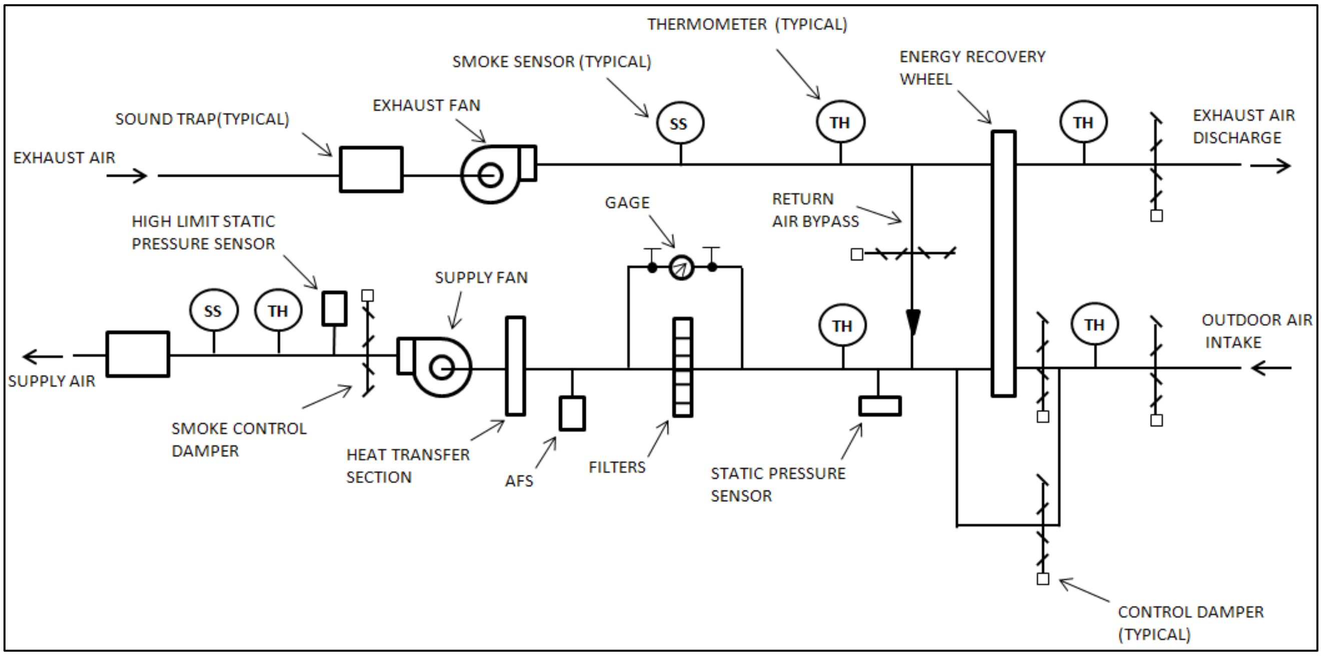



**Figure 6 – Existing Air Side System for ERU 1 – ERU 5**

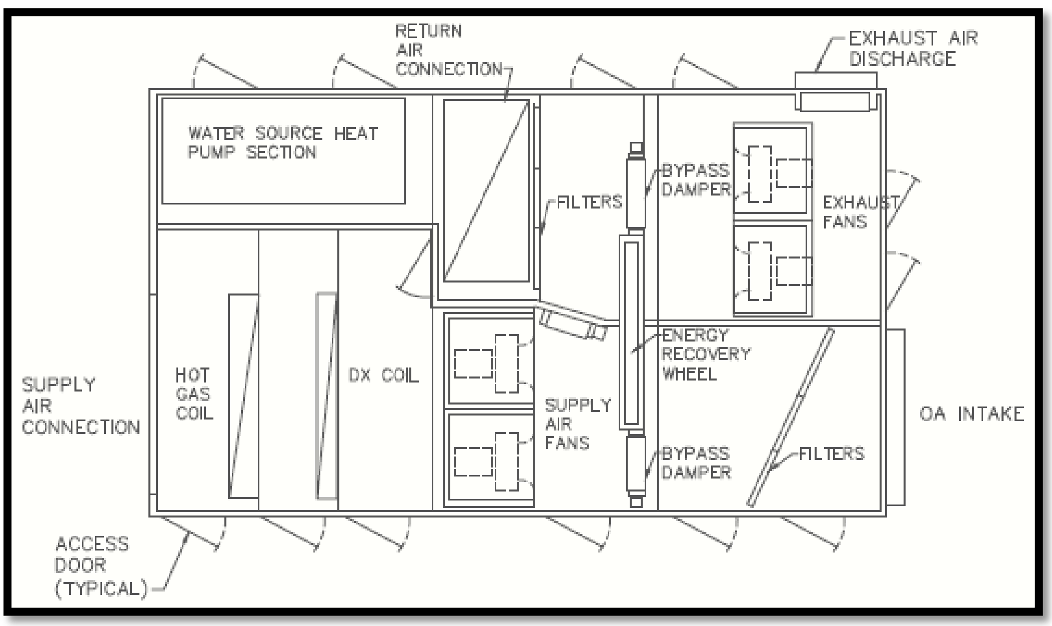



**Figure 7 – Existing Typical Energy Recovery Unit Plan**

### 4.5.2 Hot Water Heating System

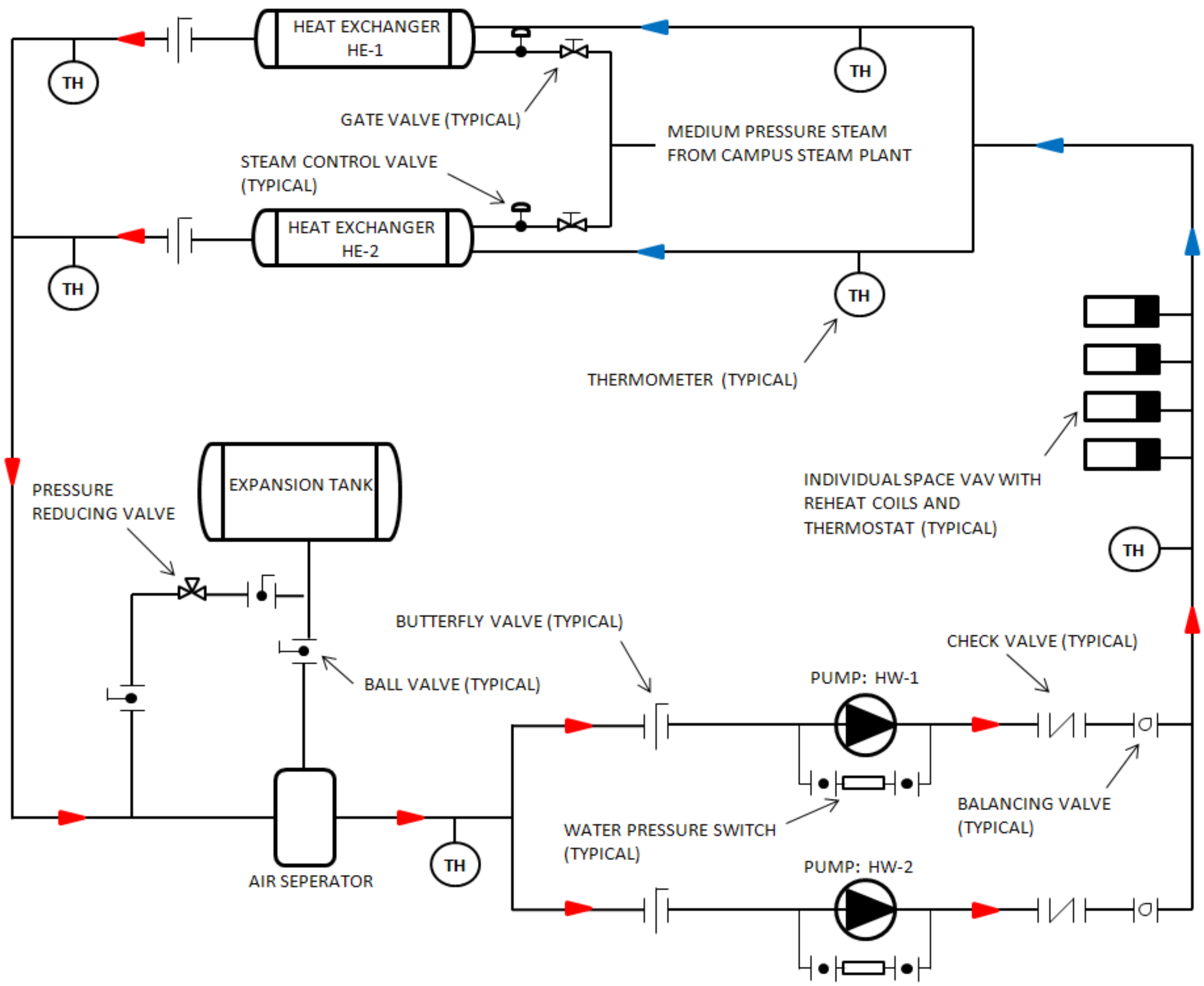



**Figure 8 – Existing Hot Water Heating System**

When heating, the campus steam plant provides the building with steam, which is taken to the heat exchangers then hot water is used to heat the building by the energy recovery units. When the heating demand is high, an auxiliary natural gas hot water heating system is used to provide sufficient heat. The water reaches the heating coils located in various spaces. Then, using variable air volume with hot water reheat coils and thermostats, the occupants have individual climate control.

### 4.5.3 Heat Transfer System

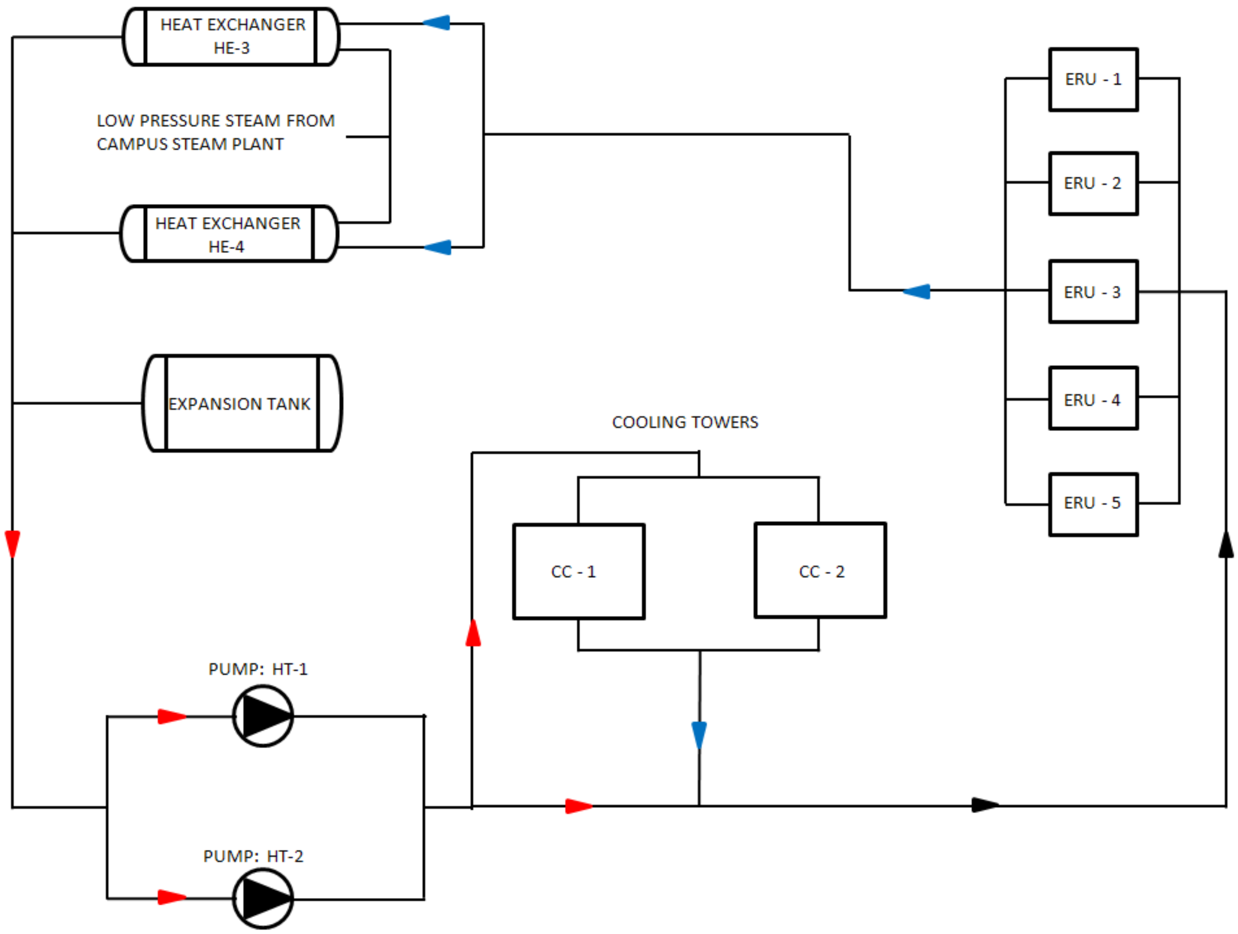



**Figure 9 – Existing Heat Transfer System**

The heat transfer system is the primary means of heating, cooling, and ventilating the building. The water circulates between the five energy recovery units, and then each unit delivers air to its respective zone. This allows for simultaneous heating and cooling throughout the building with energy being transferred between spaces in order to conserve energy. When the cooling demands are high enough, the heat transfer water loop will pass through the cooling towers to provide sufficient cooling for the building.

## 4.6 Energy Consumption and Cost Analysis

The following heating and cooling loads were calculated in TRACE 700.

**Table 6 – Peak Loads**

| Peak Loads | |
|---|---|
| Heating | 6630 Mbh |
| Cooling | 3516 Mbh |

### 4.6.1 Natural Gas

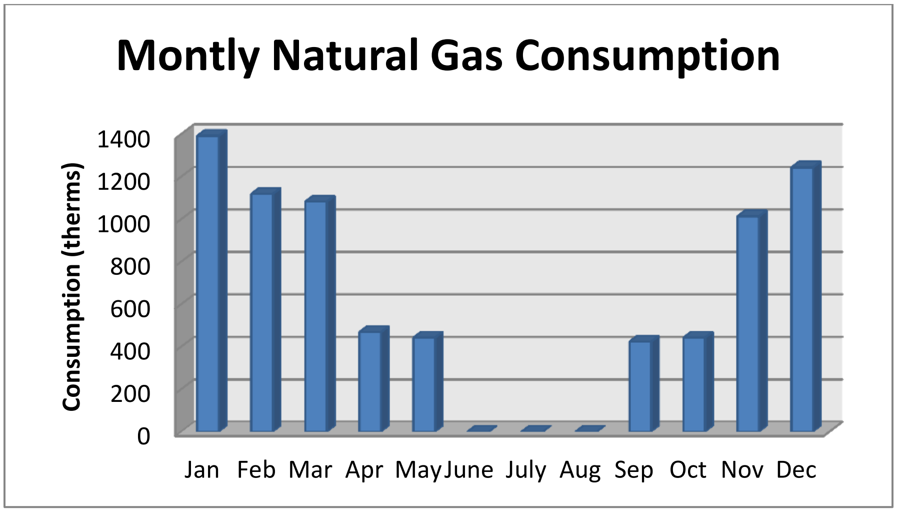



**Figure 10 – Existing Monthly Natural Gas Consumption Graph**

The figure above shows the monthly natural gas consumption rates throughout the year. As you can see, when heating loads are low enough, the hot water heat transfer system is able to completely satisfy the heating needs of the building. The building does not require any auxiliary heating, therefore uses no natural gas.

**Table 7 – Existing On Peak Monthly Natural Gas Consumption Cost Analysis**

| On Peak Monthly Natural Gas Consumption Cost Analysis | | | |
|---|---|---|---|
| Month | Consumption (therms) | Price per Therm ($) | Cost ($) |
| Jan | 1392 | 1.16 | 1614.72 |
| Feb | 1119 | 1.16 | 1298.04 |
| Mar | 1083 | 1.16 | 1256.28 |
| Apr | 469 | 1.16 | 544.04 |
| May | 443 | 1.16 | 513.88 |
| June | 0 | 1.16 | 0 |
| July | 0 | 1.16 | 0 |
| Aug | 0 | 1.16 | 0 |
| Sep | 424 | 1.16 | 491.84 |
| Oct | 443 | 1.16 | 513.88 |
| Nov | 1014 | 1.16 | 1176.24 |
| Dec | 1244 | 1.16 | 1443.04 |
| Total | 7631 | 1.16 | 8851.96 |

The cost per therm was found on the website of the U.S. Energy Information Administration website. The cost is equal to 12.01$ per cubic foot. I then converted cubic feet into BTUs, then BTUs into therms to find the cost per therm. I used the consumption in therms from the trace model to accurately find out the total monthly cost of natural gas and finally the total annual cost.

### 4.6.2 Steam

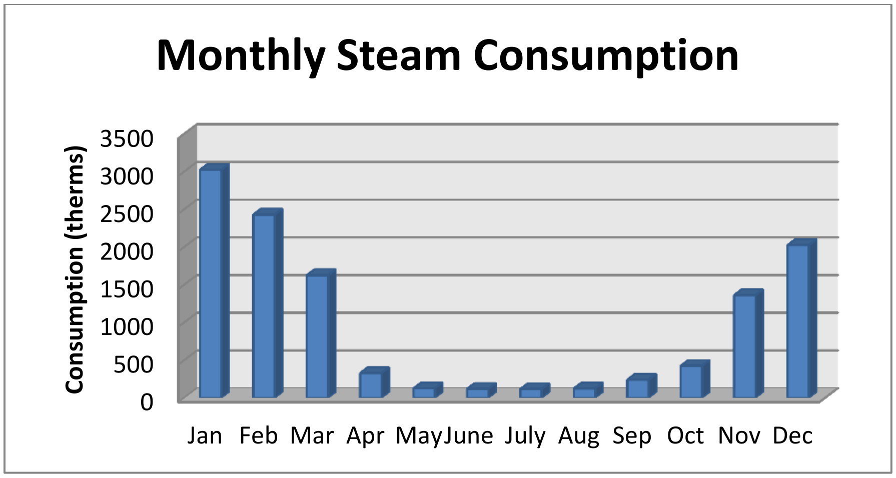



**Figure 11 – Existing Monthly Steam Consumption Graph**

The steam is provided by the Slippery Rock University Campus Steam Plant. I was able to obtain the cost of steam from the engineer in order to calculate the monthly energy costs. Figure 11 shows that there is not much use for steam in the summer with exception to provide a sufficient amount of hot water.

**Table 8 - Existing On Peak Steam Energy Consumption Cost Analysis**

| On Peak Steam Energy Consumption Cost Analysis | | | |
|---|---|---|---|
| Month | Therms | $ per therm | Cost ($) |
| Jan | 3024 | 1.057 | 3196.37 |
| Feb | 2431 | 1.057 | 2569.57 |
| Mar | 1627 | 1.057 | 1719.74 |
| Apr | 329 | 1.057 | 347.75 |
| May | 127 | 1.057 | 134.24 |
| June | 120 | 1.057 | 126.84 |
| July | 118 | 1.057 | 124.73 |
| Aug | 125 | 1.057 | 132.13 |
| Sep | 241 | 1.057 | 254.74 |
| Oct | 425 | 1.057 | 449.23 |
| Nov | 1362 | 1.057 | 1439.63 |
| Dec | 2026 | 1.057 | 2141.48 |
| Total | 11955 | 1.057 | 12636.44 |

### 4.6.3 Electricity

**Table 9 – Existing On Peak Monthly Electricity Energy Consumption Cost Analysis**

| On Peak Monthly Electricity Energy Consumption Cost Analysis | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Electrcity | | Price per kWh | | Price per kW | | Monthly Cost ($) | | Total Monthly Cost ($) |
| Month | Consumption (kWh) | Demand (kW) | 0 - 40,000 kW | > 40,000 kW | 0 - 100 kW | > 100 kW | Consumption | Demand | |
| Jan | 106050 | 288 | 0.05113 | 0.04615 | 7.04 | 6.05 | 5093.41 | 1841.40 | 6934.81 |
| Feb | 96869 | 290 | 0.05113 | 0.04615 | 7.04 | 6.05 | 4669.70 | 1853.50 | 6523.20 |
| Mar | 110241 | 282 | 0.05113 | 0.04615 | 7.04 | 6.05 | 5286.82 | 1805.10 | 7091.92 |
| Apr | 111790 | 337 | 0.05113 | 0.04615 | 7.04 | 6.05 | 5358.31 | 2137.85 | 7496.16 |
| May | 55709 | 223 | 0.05113 | 0.04615 | 7.04 | 6.05 | 2770.17 | 1448.15 | 4218.32 |
| June | 29318 | 212 | 0.05113 | 0.04615 | 7.04 | 6.05 | 1552.23 | 1381.60 | 2933.83 |
| July | 37270 | 219 | 0.05113 | 0.04615 | 7.04 | 6.05 | 1919.21 | 1423.95 | 3343.16 |
| Aug | 28512 | 205 | 0.05113 | 0.04615 | 7.04 | 6.05 | 1515.03 | 1339.25 | 2854.28 |
| Sep | 134311 | 469 | 0.05113 | 0.04615 | 7.04 | 6.05 | 6397.65 | 2936.45 | 9334.10 |
| Oct | 115106 | 317 | 0.05113 | 0.04615 | 7.04 | 6.05 | 5511.34 | 2016.85 | 7528.19 |
| Nov | 103069 | 281 | 0.05113 | 0.04615 | 7.04 | 6.05 | 4955.83 | 1799.05 | 6754.88 |
| Dec | 42094 | 106 | 0.05113 | 0.04615 | 7.04 | 6.05 | 2141.84 | 740.30 | 2882.14 |
| Total | 970339 | 469 | 0.05113 | 0.04615 | 7.04 | 6.05 | 47171.54 | 20723.45 | 67894.99 |

Table 9 shows both the consumption and demand load for electricity both monthly and annually thoughout the year. As shown in the table above, the cost of elecricity was found on the West Penn Power Company website. It provides demand energy charges for the first and second block kilowatts along with the first and second block kilowatt-hour charges for energy consumption. The total monthly costs are accurate due to the scale of the building. They are likely lower than most buildings of similar size due to the high efficient mechanical systems and lighting fixtures.

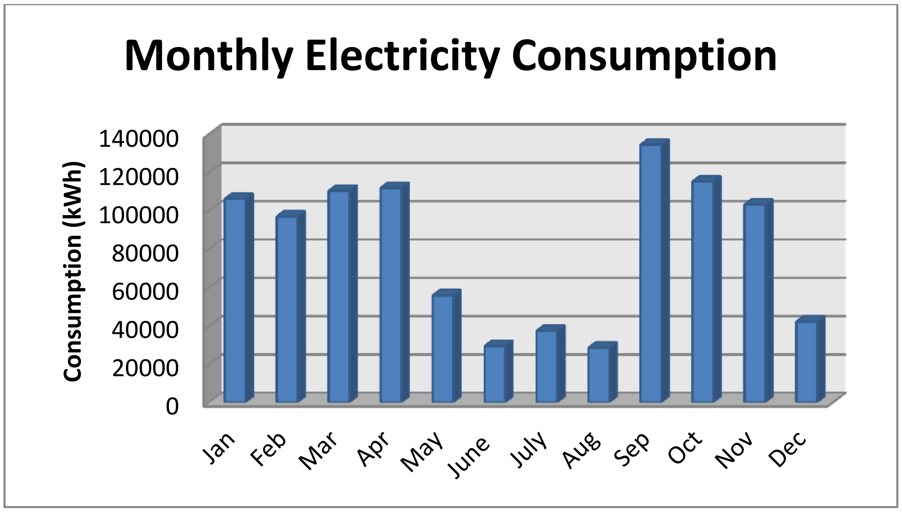



**Figure 12 – Existing Monthly Electricity Consumption Graph**

Shown in Figure 12, the electricity rates drop dramatically in December, and also during the summer months of May through August. This can be attributed to the fact that the building is part of The Slippery Rock University. There are not as many students at school in the summer compared to rest of the year based on the occupancy hours provided by the mechanical engineer. The students also are off for winter break in the December shown by the lower electricity rates.

### 4.6.4 Total Cost Analysis

**Table 10 – Existing Total Monthly and Annual Energy Cost**

| Total Monthly and Annual Energy Cost | | | | |
|---|---|---|---|---|
| Month | Natural Gas ($) | Electricity ($) | Steam ($) | Total ($) |
| Jan | 1614.72 | 6934.81 | 3196.37 | 11745.90 |
| Feb | 1298.04 | 6523.20 | 2569.57 | 10390.81 |
| Mar | 1256.28 | 7091.92 | 1719.74 | 10067.94 |
| Apr | 544.04 | 7496.16 | 347.75 | 8387.95 |
| May | 513.88 | 4218.32 | 134.24 | 4866.44 |
| June | 0.00 | 2933.83 | 126.84 | 3060.67 |
| July | 0.00 | 3343.16 | 124.73 | 3467.89 |
| Aug | 0.00 | 2854.28 | 132.13 | 2986.41 |
| Sep | 491.84 | 9334.10 | 254.74 | 10080.68 |
| Oct | 543.88 | 7528.19 | 449.23 | 8521.30 |
| Nov | 881.60 | 6754.88 | 1439.63 | 9076.11 |
| Dec | 1568.32 | 2882.14 | 2141.48 | 6591.94 |
| Total | 8712.60 | 67894.99 | 12636.45 | 89244.04 |

Once all of the energy rates were obtained, the next step was to use the amount of energy consumption for each energy source per month to find a monthly rate. Then the monthly rates of natural gas, electricity, and steam were added together to get a total monthly energy cost. The final step was to add all off the months together to get a total annual energy cost. Table 11 shows that during the first month that each semester resumes, energy costs are greatly increased. Each graph follows similar trends. Loads begin to increase around September where they tend to increase until January. They then start to decline until they are low in the summer.

### 4.6.5 Energy Consumption Summary

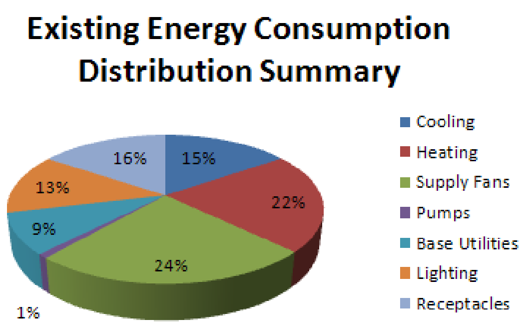


**Figure 13 – Fractional Energy Consumption Summary**

**Table 11 – Fractional Cost of Operation**

| Existing Energy Cost Distribution | | | | | |
|---|---|---|---|---|---|
| | Electric ($) | Gas ($) | Steam ($) | Total Cost ($) | Cost/SF |
| Heating | 962.47 | 4183.19 | 11278.93 | 16424.59 | 0.17 |
| Cooling | 9904.87 | | | 9904.87 | 0.10 |
| Supply Fans | 26032.04 | | | 26032.04 | 0.27 |
| Pumps | 397.67 | | | 397.67 | 0.00 |
| Base Utilities | 6982.81 | | 1357.53 | 8340.33 | 0.09 |
| Lighting | 13789.06 | | | 13789.06 | 0.14 |
| Receptacles | 9826.02 | 4529.41 | | 14355.43 | 0.15 |
| Totals | 67894.93 | 8712.60 | 12636.46 | 89243.99 | 0.91 |

## 4.7 Overall Evaluation of Mechanical System

The Slippery Rock University Student Union will be attempting to achieve a LEED Rating. The building will hope to score 54 points, which puts it between 50 to 59 points achieving LEED Silver. The designed building has been compared to a baseline model and reports that it will save an estimated 28 percent of total energy on an annual basis allowing for 9 points in the Energy and Atmosphere category. This lower energy consumption allows the SRU Student Union to have the potential to reach LEED Silver rating.

Due to the nature of the building, the energy recovery unit system seems that it can provide thermal comfort and wellbeing to its occupants effectively. With an auxiliary heating and cooling system, the building is capable of using minimal energy while being able to satisfy comfort needs during peak load conditions throughout the entire year. Most spaces are equipped with thermostats that allow for the occupants to control the climate by the VAV with reheat coils.

Overall, the majority of the results appear to be reasonable to the actual design conditions with variation in some cases. The variances can be attributed to the assumptions made in the model. It seems the building has a mechanical system that is considerably oversized in some zones. This is an issue that is hoped to be corrected in the mechanical redesign.

# 5.0 Overview of Proposed Mechanical Redesign

## 5.1 Introduction

The general intent of the mechanical depths along with the construction and structural breadths is to maintain and improve efficiencies as well as to value engineer the project as a whole. Changing a number of aspects from the existing building design to incorporate less building materials and green design has carried out this process.

## 5.2 DOAS with Active Chilled Beams

The mechanical redesign will be evaluating the effects of replacing the current mechanical system with a dedicated outdoor air system with active chilled beams. This redesign will explore the energy savings created by supplying only the minimum amount of outdoor air to fulfill ventilation requirements from ASHRAE Standard 62.1 in specific areas of the building. It incorporates green design by downsizing the air handling units required to move only the ventilation air required through the building along with using less sheet metal for the ductwork within the building, decreasing the amount of material being used. The redesign will explore the benefits and feasibility of using such a system along with a cost analysis of the additional equipment used to determine a payback period.

## 5.3 Solar Thermal Water Heating System

The purpose of the Solar Thermal Water Heating System design is an attempt to explore the feasibility of replacing the domestic hot water needs provided through the campus steam plant. A study will be conducted in order to determine whether the system output, initial cost, and payback period are worth incorporating the additional system.

# 6.0 DOAS with Active Chilled Beams – Mechanical Depth

## 6.1 Redesign Objective

The main objective of the mechanical system redesign is to explore the effects of replacing a portion of the spaces with a dedicated outdoor air system with active chilled beams. Occupant comfort and control is a major consideration in the overall design process, thus the benefits of such a system will be evaluated. The redesign will focus on using chilled beams to adequately and comfortably cool the individual spaces although they are also capable of heating the space as well.

## 6.2 DOAS with Active Chilled Beam System Design and Evaluation

### 6.2.1 Active Chilled Beams Background Information

Advantages:

- Uses considerably less supply air allowing for smaller ductwork and air handling units.
- Potentially reduces building construction costs by lower floor to floor heights.
- Minimal maintenance required because there are no moving parts or filters.
- Increases overall occupant comfort with uniform space temperature, individual temperature control, and lower system noise.
- Reduces energy consumption by a reduction in fan energy and higher designed chilled water temperature.
- Ideal for energy recovery wheels.

Disadvantages:

- Increased construction and initial cost compared to VAV system.
- Increased ceiling space consumed compared to a traditional diffuser.
- Humidity must be carefully controlled to prevent condensation from occurring.

Chilled beams operate by a means of convection and induction. The figure below shows a diagram of how the air in the space enters the cavity in the chilled beam where it mixes and is pulled back into the space with the supply air. It is cooled by passing over the chilled water coils prior to being released back into the room. The ratio between the air in the room and outdoor ventilation air is typically between 3 and 6 times the amount of primary supply air.

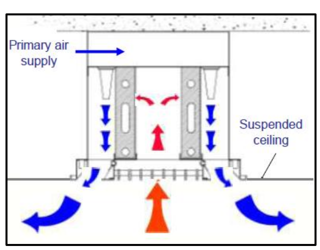



**Figure 14 – Section of a Typical Active Chilled Beam**

The energy savings come from several different aspects that make chilled beams an efficient system to incorporate into HVAC design. One reason why chilled beams are so effective is because the chilled water has a much larger cooling capacity when compared to air. Therefore, less chilled water is needed to get an equal amount of cooling. Another area where energy savings come from is the temperature of the chilled water needed for cooling. Due to the nature and operation of chilled beams, an elevated chilled water temperature is possible, in turn using less energy to lower the chilled water supply temperature.

### 6.2.2 Design Considerations

The buildings mechanical system has several important issues to address in order to provide a clean and healthy indoor environment. First, the HVAC system must be able to remove the sensible loads of the space. This will be taken care of by the use of the active chilled beams in the individual spaces. The system must also provide an adequate amount of outdoor air to properly ventilate the space in accordance with ASHRAE Standard 62.1. Last, the air must be dehumidified to accommodate for the latent heat gains of the space.

Three different energy saving techniques were implemented into the redesign resulting in a considerable amount of energy saved. The first aspect was to use of an enthalpy wheel. Using this enthalpy wheel helps to recover otherwise wasted energy from the exhaust air. This is useful because it preheats or preconditions and also exchanges humidity to the incoming outdoor air therefore less energy is needed by the main heating or cooling coils of the AHU.

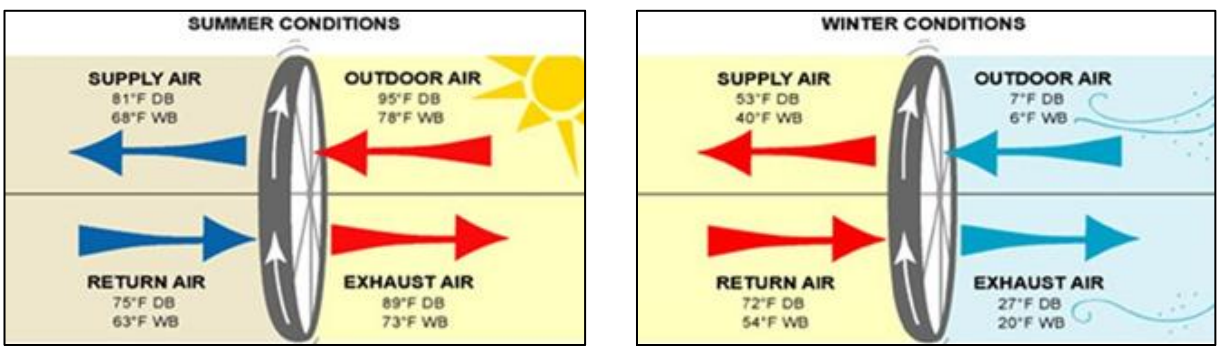



**Figure 15 – Enthalpy Wheel Diagram**

Another technique used to cut energy costs is to assign a portion of the building to a dedicated outdoor air system. This system is more efficient because it typically only requires 50% - 65% of the total amount of air to be pushed through the building when compared to a traditional air handler. This is because the dedicated outdoor air system is sized based off of the ventilation requirements of the spaces it serves. Consequently, pushing less air through the building allows fewer air handlers along with a smaller amount of ductwork, which in turn conserves energy and resources.

The last items used to achieve a better energy performance are the active chilled beams used in the redesign. The chilled beams offer a high level of sensible cooling by the chilled water that flows through the beams cooling the air passing over the pipes. The chilled beams also allow for better stratification of air into the space resulting in enhanced comfort.

### 6.2.3 System Design

The first step in the design process was to determine what areas of the building were going to use chilled beams as a means of heating and cooling based on the location and function of each space. For simplicity's sake in design and energy modeling, the zones were kept the same and specific energy recovery units were then assigned to DOAS with active chilled beams. The following sketches show the portions of the building with the new DOAS with chilled beams as well as the systems remaining from the existing design.

| | |
|---|---|
| Zone 1 - Green: Heating Only | Zone 4 - Dark Blue: DOAS |
| Zone 2 - Purple: ERU 4 | Zone 5 - Red: Ductless Split System |
| Zone 3 - Yellow: ERU 2 | Zone 6 - Pink: MUA |

**Figure 16 – Legend of Zone Redesign**

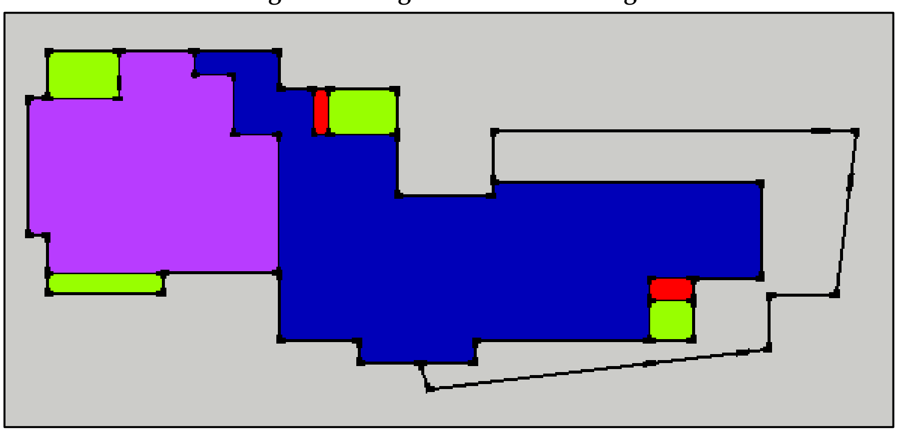


**Figure 17 – Third Floor Zone Redesign**

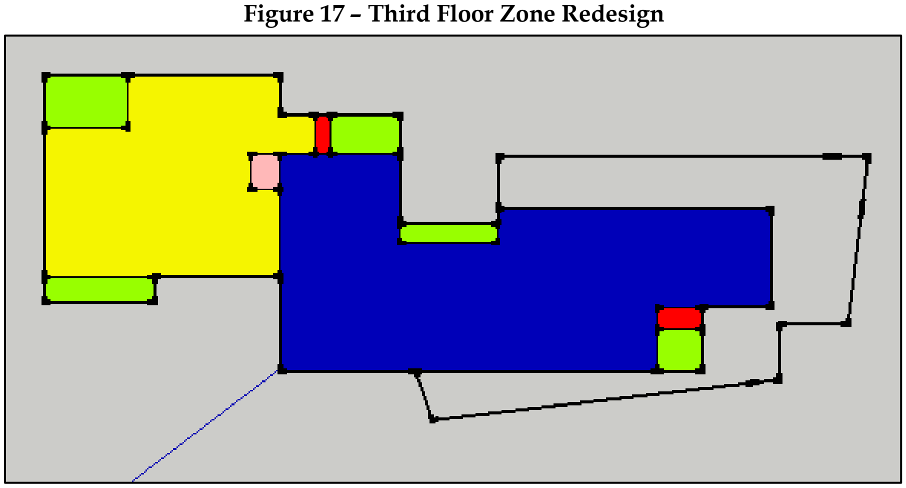


**Figure 18 – Second Floor Zone Redesign**

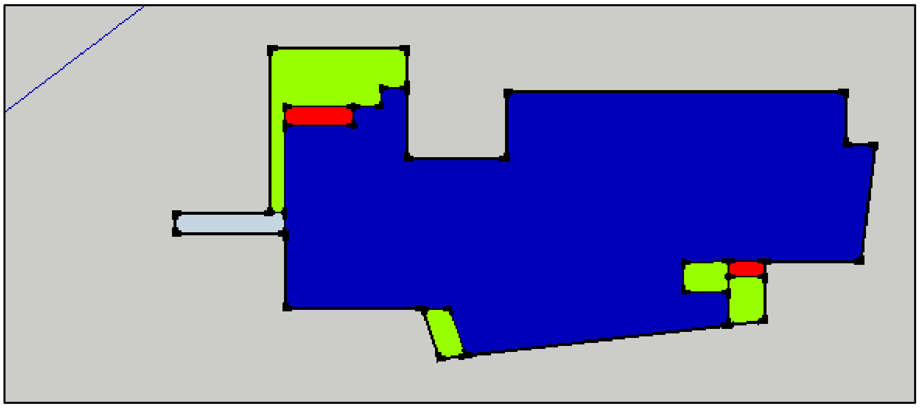


**Figure 19 – First Floor Zone Redesign**

The new layout allows for energy recovery units ERU-1, ERU-3, and ERU-5 to be consolidated into a single air handler providing proper ventilation to all the spaces that will use chilled beams. The air handler located on the first floor was able to be removed. This was possible because although it was located on the first floor, an existing outdoor air supply duct runs from the roof directly to the air handler. The duct was able to be downsized due to the lower amount of supply air being taken to the spaces. After the zones were finalized, the new system was designed and evaluated. The floor diagram below visually illustrates the redesign.

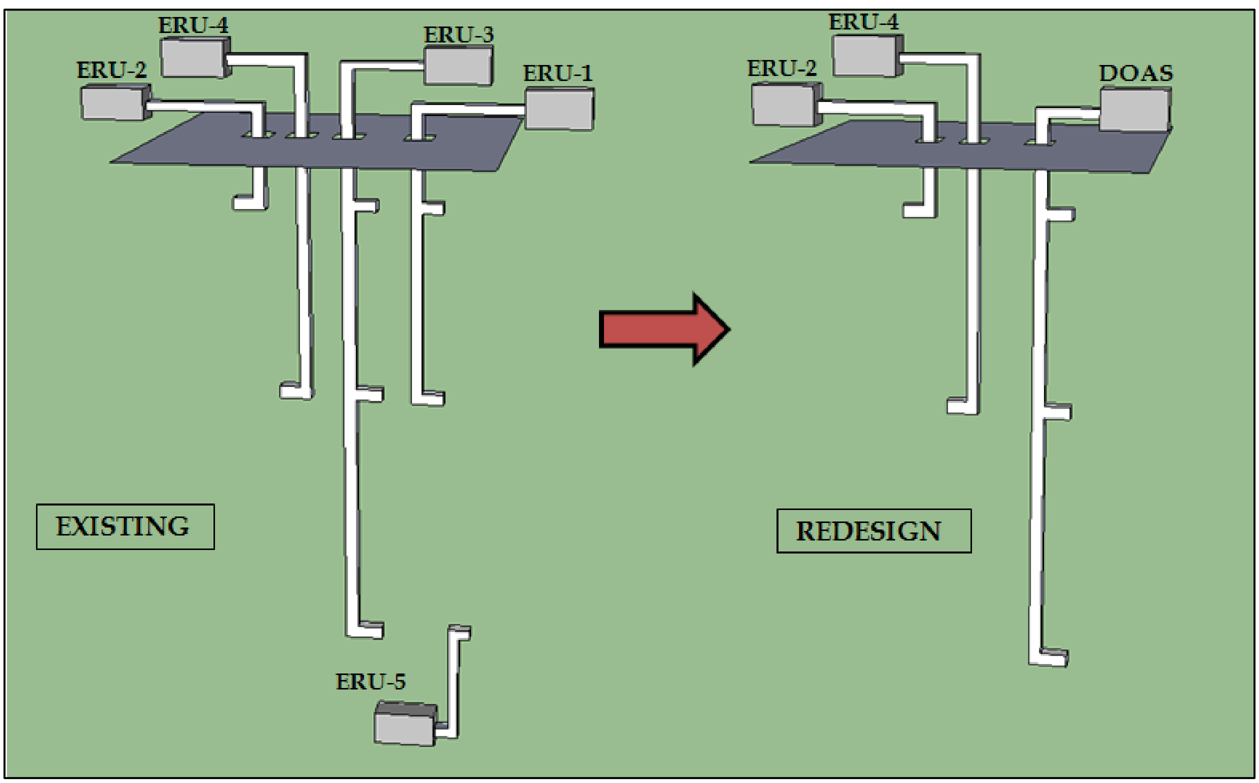



**Figure 20 – Existing vs. Redesign Riser Diagram**

When designing the active chilled beam system, several design considerations were taken into account in order to achieve occupant comfort and to prevent condensation from occurring. The following table shows the space summer design conditions for cooling.

| Space | | | Outdoor Air Supply | |
|---|---|---|---|---|
| $T_{DB}$ | 75 °F | | $T_{DB}$ | 55 °F |
| RH | 50% | | RH | 50% |
| D.P. | 55 °F | | D.P. | 37 °F |
| $W_{SP}$ | 65 gr/lb | | $W_{OA}$ | 32 gr/lb |

**Figure 21 –Design Conditions**

The first step in sizing the new dedicated outdoor air system with active chilled beams was to determine the amount of outdoor supply air needed to each space. This process was carried out through calculating the minimum ventilation required through ASHRAE Standard 62.1 based on the size of each room and the number of occupants per room. Also, calculations were performed to find the air flow rate needed to satisfy the latent load requirement per space. The design was then based off which ever value was higher to satisfy humidity and ventilation requirements and set as the outdoor requirement per room in the TRACE 700 model. The method of calculating the air flow rate for the latent load is shown below.

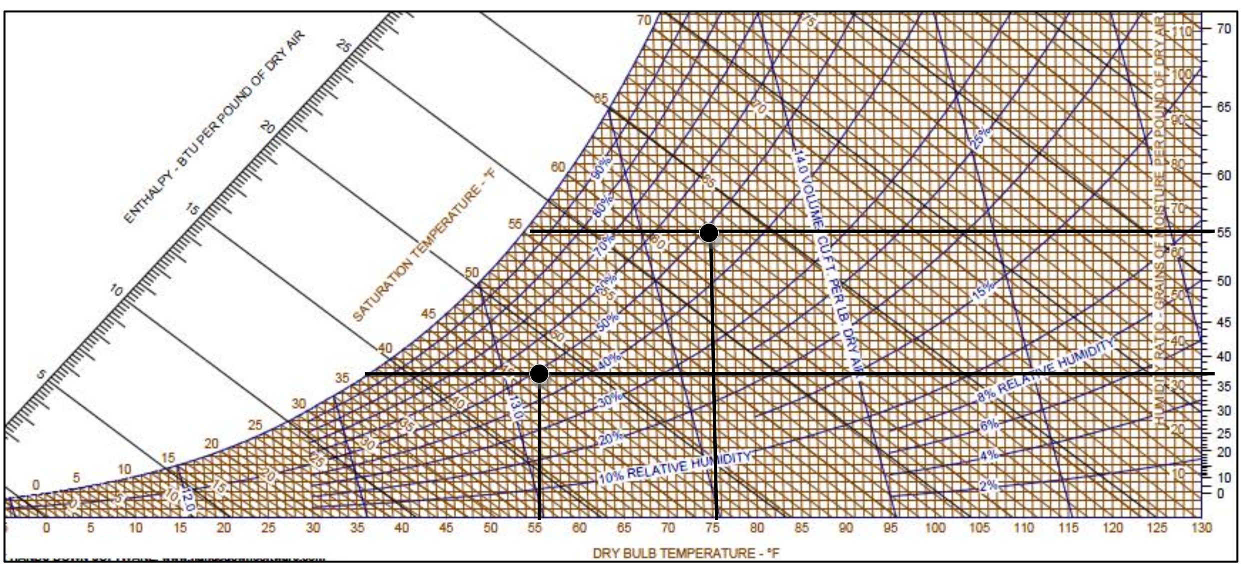



**Figure 22 – Psychometric Chart with Design Conditions**

Using the equation:

$cfm_{SA} = h_L / .68(w_{SP} - w_{OA})$

where $h_L$ = (200 btuh/person) x (# of people)

The total air volume flow rate was found for each space. The table showing each spaces design requirements can be found at the end of the report in Appendix C.

The next step in designing the DOAS system with chilled beams was to select chilled beams from manufacturer data that can adequately meet the sensible load and minimum outdoor air requirements for each space it is applied to. The sensible loads for each room were found by modeling the building in TRACE 700 after being assigned to the dedicated outdoor air system with chilled beams. Each room being assigned to the dedicated outdoor air system has the minimum flow rates manually put in. The follow figure is an example of the information from TRACE 700 that was used to size chilled beams for each space.

COOLING COIL SELECTION

| | Total Capacity ton | Total Capacity MBh | Sens Cap. MBh | Coil Airflow cfm |
|---|---|---|---|---|
| Main Clg | 0.1 | 1.1 | 1.1 | 50 |
| Aux Clg | 0.1 | 1.2 | 1.2 | 189 |

**Figure 23 – Example from TRACE 700 Room Design**

Figure 24 below from TROX USA Inc. was used to select the chilled beams for each space. The primary airflow is outdoor air supplied to the space and the aux cooling is the cooling that must be supplied by the chilled beam to the space. In some instances the amount of outdoor air was increased in order to meet the cooling load. This increase in outdoor air supply was included when sizing the air handler. The chilled water supply temperature will be 57 $^{o}$F in order to remain above of the room dew point of 55 $^{o}$F and to be 18 $^{o}$F above the temperature of the space in which the cooling capacities below are based on. The chilled water will raise a minimum 3 $^{o}$F and maximum of 6 $^{o}$F after the supply air passes over the chilled water piping. The values in the tables show the variance from different air flow rates. As the air flow decreases, the cooling capacity increases. The following equation is used to determine the capacity of the chilled beams based on a chilled water flow rate of 1.5 gpm.

$q = 500\ gpm\ \Delta T$

$q = 500 \times 1.5 \times 3 = 2250$ btuh

$q = 500 \times 1.5 \times 6 = 4500$ btuh

| Active Beam Series | Nozzle Type | Induction Ratio [1] | Primary Airflow CFM/LF | $\Delta P_{AIR}$ inches $H_2O$ | Maximum Chilled Water Flow Rate (GPM) | NC | Secondary Cooling [2] | | Total Cooling [3] | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | BTUH/LF | BTUH/CFM | BTUH/LF | BTUH/CFM |
| DID-302-US | A | 5.3 | 5.0 | 0.19 | 1.5 | <15 | 247 | 49.4 | 356 | 71.2 |
| | | | 8.0 | 0.48 | | 23 | 360 | 45.0 | 534 | 66.8 |
| | | | 11.0 | 0.91 | | 32 | 433 | 39.3 | 672 | 61.1 |
| | B | 4.2 | 8.0 | 0.18 | | <13 | 316 | 39.5 | 490 | 61.3 |
| | | | 13.0 | 0.47 | | 26 | 419 | 32.2 | 702 | 54.0 |
| | | | 18.0 | 0.91 | | 35 | 504 | 28.0 | 896 | 49.8 |
| | C | 3.2 | 13.0 | 0.22 | | 18 | 347 | 26.7 | 630 | 48.5 |
| | | | 19.0 | 0.47 | | 28 | 432 | 22.7 | 846 | 44.5 |
| | | | 25.0 | 0.81 | | 36 | 505 | 20.2 | 1050 | 42.0 |

**Figure 24 – Chilled Beam Performance Chart**

The total air flow rate needed for the DOAS system for each space was then found and totaled to select a proper sized air handler with an adequate cooling capacity. An air handler was then sized using TOPSS, an equipment sizing program from Trane. Table 12 shows the amount of outdoor air needed from each existing air handler to provide proper ventilation to each space.

**Table 12 – Chilled Beam Performance Chart**

| Zone | OA Supply (cfm) | Cooling (tons) |
|---|---|---|
| ERU-3 Meeting Rooms | 10808 | 15.3 |
| ERU-5 Bookstore | 2432 | 19.5 |
| ERU-1 Lobby areas | 9603 | 8.1 |
| TOTAL | 22843 | 42.9 |

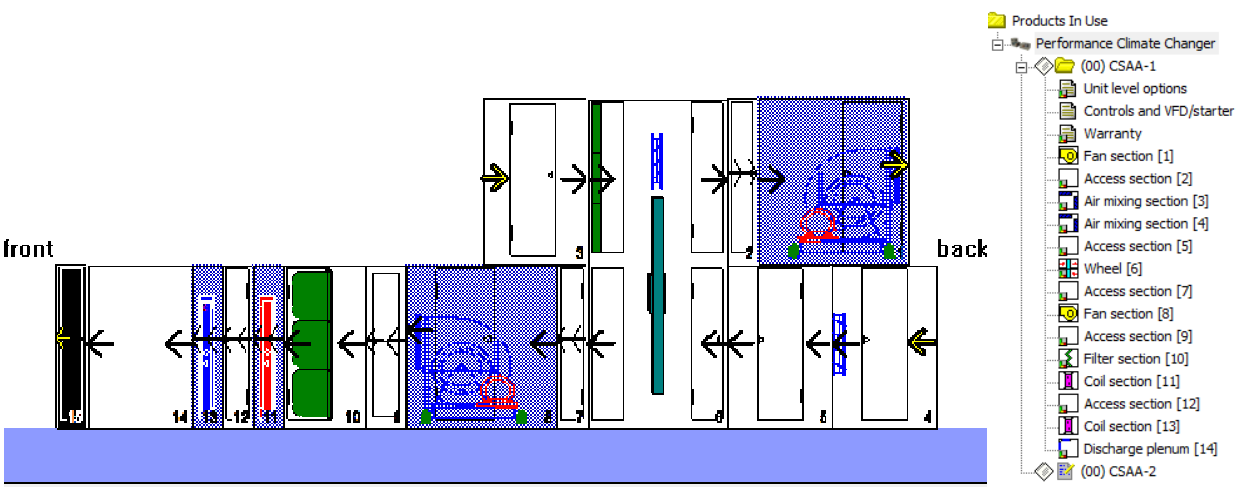



**Figure 25 – Chilled Beam Performance Chart**

Figure 25 above is a 100% outdoor air handler designed to carry 24000 cfm of supply air to the zones selected previously in the report. The new air handler is equipped with an enthalpy wheel that will transfer energy from the exhaust air to the outdoor supply air.

### 6.2.4 Redesign Schematics

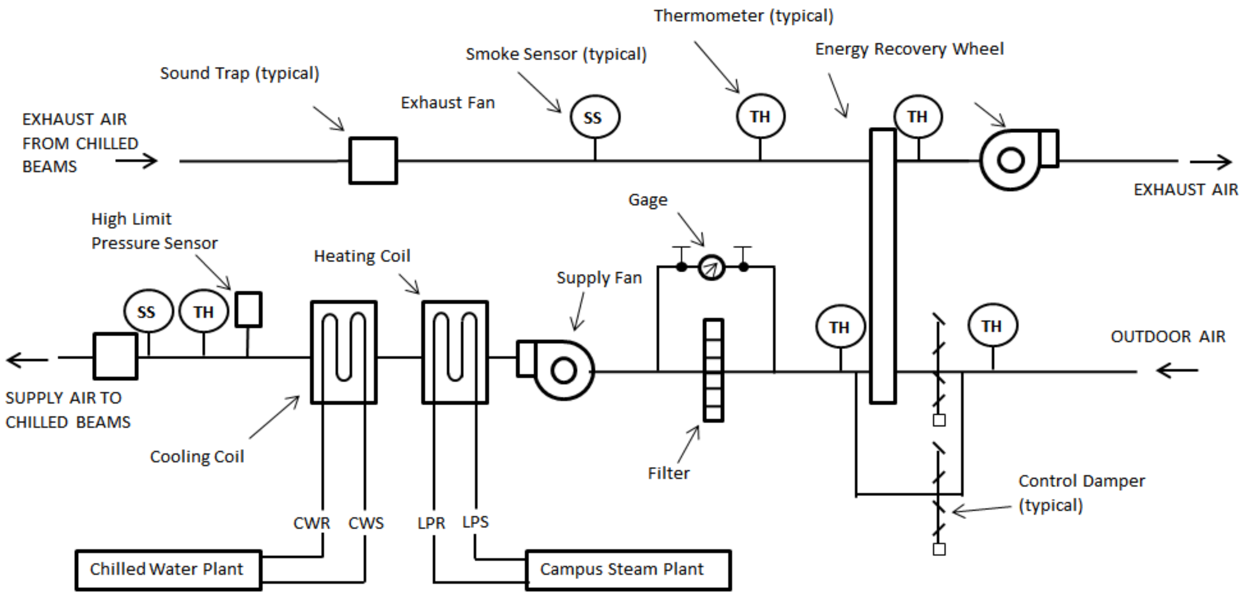



**Figure 26 – Air Side DOAS Schematic**

Figure 26 shows an air side schematic of the new air handler that will be supplying the assigned spaces with 100% outdoor air. The cooling coil will be supplied with chilled water at a temperature of 45 °F and leaving the coil at 55 °F. The chilled water will be supplied by the district chilled water plant. The heating coil will use low pressure steam to heat the incoming outdoor air from the campus steam plant. Details from sizing the air handler can be found at the end of the report in Appendix D.

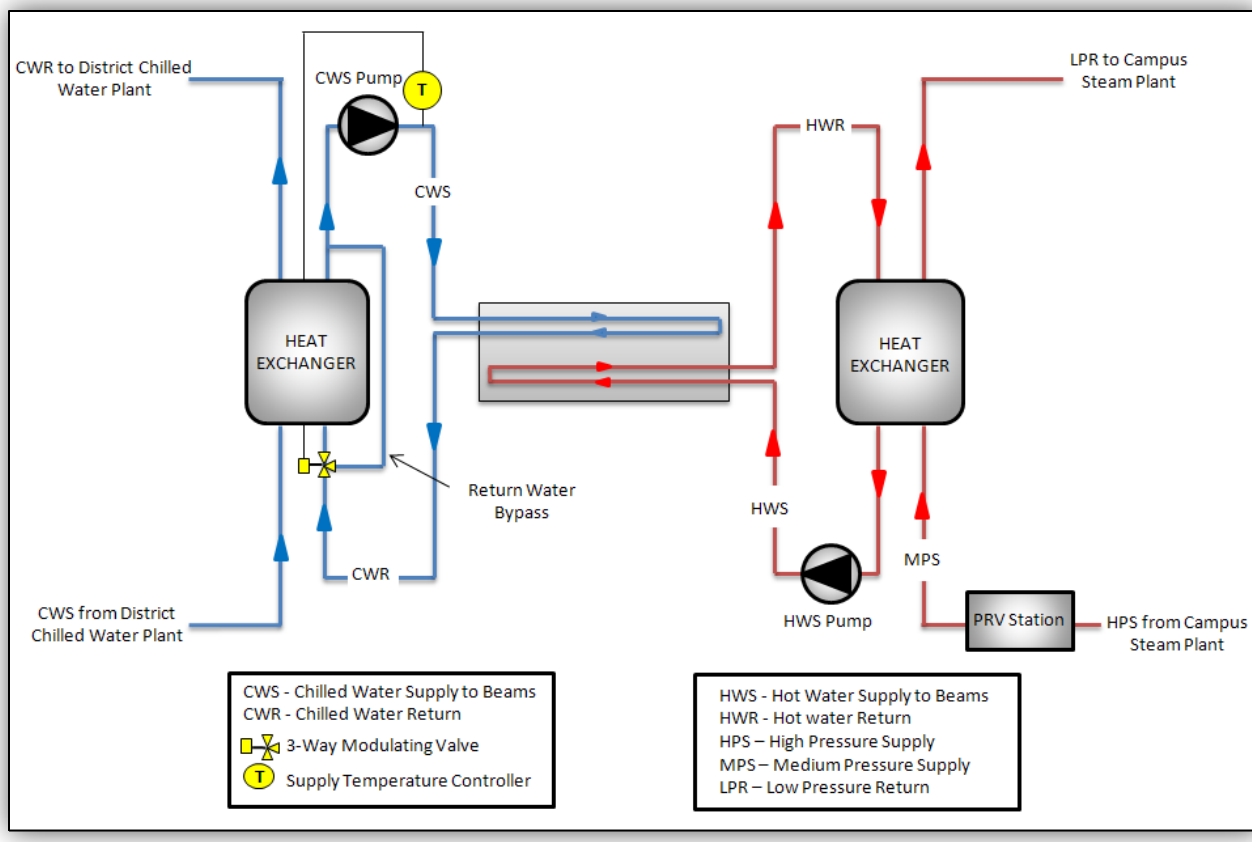



**Figure 27 – Chilled and Hot Water Chilled Beam Schematic**

This schematic demonstrates the chilled beam system to be used in the redesign. For cooling purposes, the district chilled water plant will supply the SRU Student Union with chilled water. As shown above, a heat exchange will be used to provide for sufficient chilled water to the beams. When the chilled water temperature remains at a satisfactory cooling level, the return bypass can be utilized via the 3-way modulating valve. After the chilled water heat exchanger, the chilled water supply to the chilled beams will be at 57 °F in order to provide proper cooling to the space and to remain above the space dew point avoiding condensation on the chilled beams from forming.

The heating system used in the active chilled beams will be supplied by the campus steam plant. Similar to the cooling section, a heat exchanger will heat the water flowing through the chilled beams to allow for proper space heating.

Table 13 – Chilled Beams Schedule

| Chilled Beams Schedule | | | | | |
|---|---|---|---|---|---|
| Unit Tag | Induction Ratio | Primary Airflow | ΔP | Water Flow Rate | Cooling Capacity |
| | | (cfm/lf) | (in wg) | (gpm) | (btuh/cfm) |
| DID-302-US | 5.3 | 5 | 0.19 | 1.5 | 49.4 |
| DID-602-US | 5.3 | 10 | 0.89 | 1.5 | 63.4 |
| DID-302-US | 5.3 | 11 | 0.91 | 1.5 | 39.3 |
| DID-302-US | 4.2 | 18 | 0.91 | 1.5 | 28.0 |
| DID-302-US | 3.2 | 13 | 0.22 | 1.5 | 26.7 |
| DID-302-US | 3.2 | 19 | 0.47 | 1.5 | 22.7 |
| DID-302-US | 3.2 | 25 | 0.81 | 1.5 | 20.2 |

Table 14 – Chilled Water Pump Schedule

| Chilled Water Pump Schedule | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Tag | Service | Location | GPM | Total Head (ft) | Motor HP | Efficiency | RPM | Electrial Char. | Type |
| CW - 1 | Chilled Water-Beams | Mech Room | 330 | 90 | 10 | 75 | 1750 | 480V-3ϕ-60Hz | End Suction |
| CW - 2 | Chilled Water-Beams | Mech Room | 330 | 90 | 10 | 75 | 1750 | 480V-3ϕ-60Hz | End Suction |

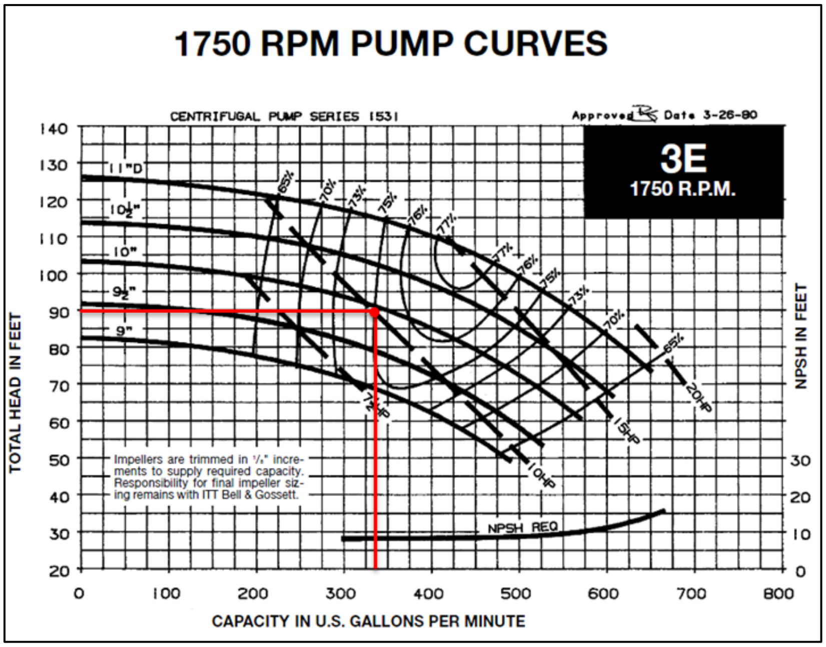



Figure 28 – Bell and Gossett Pump Series 1531 Performance Curves

### 6.2.5 Redesign Energy Consumption and Cost Analysis

The information in this section was calculated by modeling the building in TRACE 700 to find the energy consumption for the building over the course of a year. The following chart shows the energy source distribution of the building.

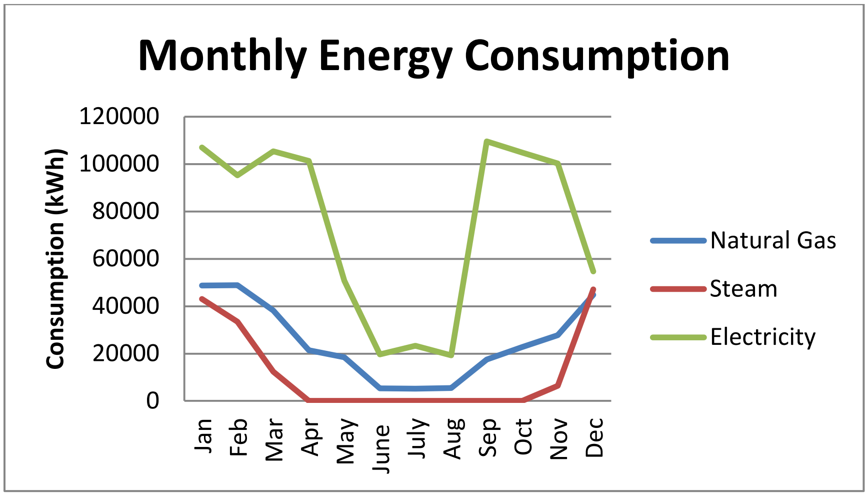



**Figure 29 – Monthly Chilled Water Consumption of Redesign**

Figure 29 shows much less energy is consumed during the summer months when the students will not be on campus. This trend appears to be logical based on occupation rates provided by the mechanical engineers. A large step occurs in September when school resumes and remains fairly consistent throughout the academic months. As you can see, natural gas is used as a means of heating; therefore, the use of natural gas is significantly higher in the winter months in order to keep the building at a desirable temperature. As shown in the figure above, steam consumed from the campus steam plant is low until the heating season occurs throughout the winter months. Detailed energy and cost tables can be found at the end of the report in Appendix A.

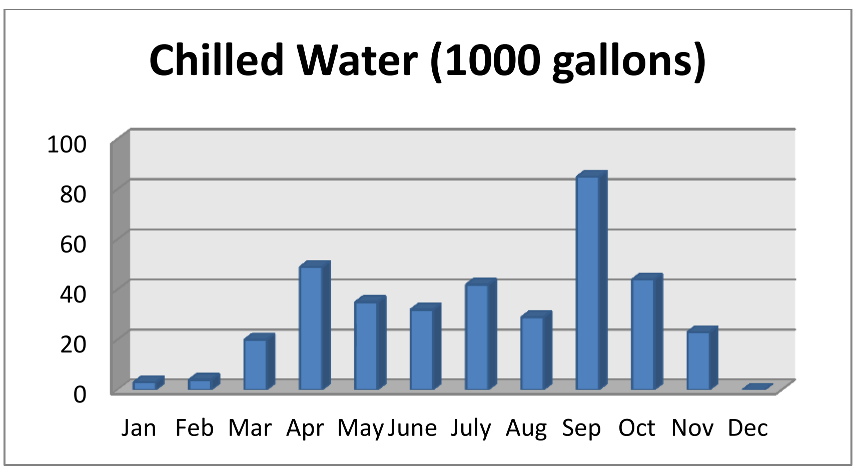



**Figure 30 – Monthly Chilled Water Consumption of Redesign**

Figure 30 shows the distribution of chilled water consumed throughout the year. The chilled water is a primary means of cooling a majority of the spaces so the trend increased as summer approaches.

Once the total energy consumption was determined, an overall distribution of cost was analyzed and a total energy cost per month and year was calculated.

**Table 15 – Total Energy Cost and Consumption of Redesign**

| Total Monthly and Annual Energy Cost | | | | | |
|---|---|---|---|---|---|
| Month | Natural Gas ($) | Electricity ($) | Steam ($) | Water ($) | Total ($) |
| Jan | 1931.40 | 6984.15 | 1550.62 | 17.61 | 10483.78 |
| Feb | 1932.66 | 6606.43 | 1207.09 | 23.48 | 9769.66 |
| Mar | 1513.80 | 6911.69 | 445.00 | 153.12 | 9023.61 |
| Apr | 849.12 | 6886.47 | 0.00 | 316.17 | 8051.76 |
| May | 729.64 | 3834.05 | 0.00 | 234.01 | 4797.70 |
| June | 211.12 | 2209.07 | 0.00 | 216.40 | 2636.59 |
| July | 207.64 | 2383.01 | 0.00 | 275.09 | 2865.74 |
| Aug | 219.24 | 2167.61 | 0.00 | 198.79 | 2585.64 |
| Sep | 694.84 | 7626.89 | 0.00 | 527.46 | 8849.19 |
| Oct | 902.48 | 7073.86 | 0.00 | 286.83 | 8263.17 |
| Nov | 1099.68 | 6710.18 | 233.60 | 176.09 | 8219.55 |
| Dec | 1775.96 | 4236.32 | 1699.66 | 0.00 | 7711.94 |
| Total | 12067.58 | 63629.73 | 5135.97 | 2425.05 | 83258.33 |

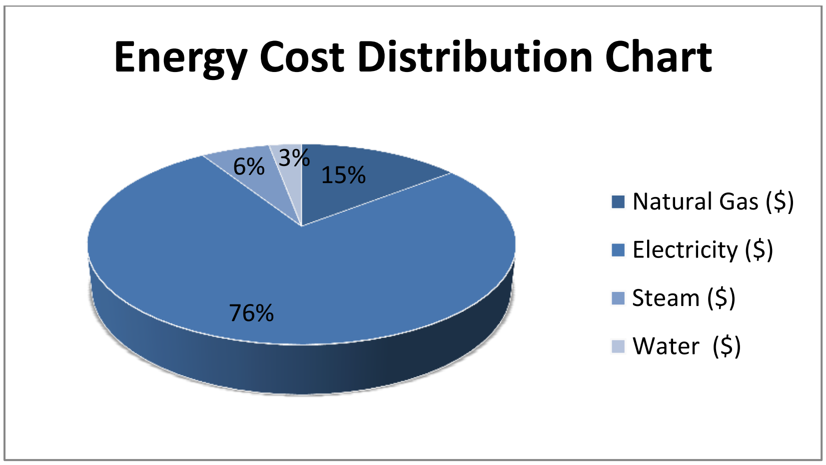



**Figure 31 – Utility Cost Distribution of Redesign**

As shown in the pie chart above, the majority of the energy costs are from the electricity consumption in the building. The table below shows where the energy is consumed along with a cost per square foot for energy of the building.

**Table 16 – Energy Cost Distribution of Redesign**

| Redesign Energy Cost Distribution | | | | | | |
|---|---|---|---|---|---|---|
| | Electric ($) | Gas ($) | Steam ($) | Water ($) | Total Cost ($) | Cost/SF |
| Heating | 3731.10 | 5054.29 | 5135.97 | | 13921.36 | 0.14 |
| Cooling | 7192.90 | | | 2076.47 | 9269.37 | 0.09 |
| Supply Fans | 13007.04 | | | | 13007.04 | 0.13 |
| Pumps | 659.37 | | | | 659.37 | 0.01 |
| Base Utilities | 10423.98 | 2511.65 | | | 12935.63 | 0.13 |
| Lighting | 16489.62 | | | | 16489.62 | 0.17 |
| Receptacles | 12125.72 | 4501.64 | | | 16627.36 | 0.17 |
| Totals | 63629.73 | 12067.58 | 5135.97 | 2076.47 | 82909.75 | 0.85 |

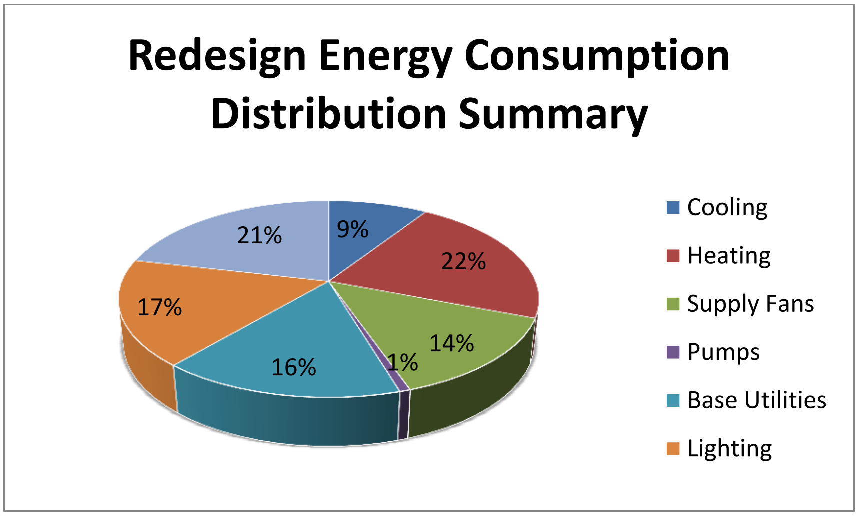



**Figure 32 – Energy Distribution of Redesign**

## 6.3 System Comparison

Due to the reduction in the amount of supply air being pushed through the building, less sheet metal is required in ductwork. A detailed ductwork quantity takeoff was conducted in Autodesk Quantity Takeoff in order to determine the amount of sheet metal that will be saved with the redesign. After finding the total amount of sheet metal used with the three air handlers being replaced, an estimate of the amount of sheet metal needed for the new ventilation rates was calculated per space. The ductwork was sized based on the air flow rate and number of chilled beams in each space using the same duct sizing schedule as the existing design. The tables below show a detailed quantity takeoff for the existing design and the redesign of the second floor in order to obtain the total pounds of sheet metal. The ratio between the existing and redesign calculated will be applied to the remaining existing sheet metal used in the applicable zones to get an estimate of the total sheet metal saved from the redesign.

**Table 17 – Existing Sheet Metal Ductwork Takeoff**

| Exisitng Sheet Metal Ductwork Takeoff (Second Floor East) | | | | | |
|---|---|---|---|---|---|
| Large Dim | Small Dim | Length (lnft) | Gage Number | Pounds/SF | Pounds of SM |
| 10 | 4 | 77 | 24 | 0.975 | 175 |
| 10 | 6 | 17 | 24 | 0.975 | 44 |
| 12 | 5 | 51 | 24 | 0.975 | 141 |
| 12 | 6 | 59 | 24 | 0.975 | 173 |
| 12 | 8 | 19 | 24 | 0.975 | 62 |
| 14 | 5 | 24 | 24 | 0.975 | 74 |
| 14 | 6 | 200 | 24 | 0.975 | 650 |
| 14 | 7 | 118 | 24 | 0.975 | 403 |
| 14 | 8 | 36 | 24 | 0.975 | 129 |
| 14 | 10 | 64 | 24 | 0.975 | 250 |
| 16 | 8 | 8 | 24 | 0.975 | 31 |
| 16 | 10 | 57 | 24 | 0.975 | 241 |
| 18 | 12 | 11 | 24 | 0.975 | 54 |
| 12 | 3.14 | 16 | 24 | 0.975 | 49 |
| 14 | 3.14 | 44 | 24 | 0.975 | 157 |
| 16 | 3.14 | 42 | 22 | 1.22 | 215 |
| 18 | 3.14 | 25 | 22 | 1.22 | 144 |
| 20 | 3.14 | 70 | 22 | 1.22 | 447 |
| 24 | 3.14 | 35 | 22 | 1.22 | 268 |
| | | | | Total | 3705 |

The following table is an example of how the sheet metal redesign was evaluated. Below are the spaces of the second floor east plan with the new ventilation rates and ductwork sizes along with the length required to reach the chilled beams from the main supply duct.

**Table 18 – Redesign Sheet Metal Ductwork Assignments**

| Redesign Sheet Metal Ductwork Assignments | | | | | |
|---|---|---|---|---|---|
| Room # | Room Name | CFM | Large Dim | Small Dim | Length |
| 236 | Student Lounge | 198 | 12 | 5 | 25 |
| 236 | Work Area | 1650 | Circular Ductwork in Takeoff | | |
| 237 | Student Orgs | 132 | 10 | 5 | 24 |
| 238 | Student Orgs | 198 | 12 | 5 | 21 |
| 239 | Student Orgs | 198 | 12 | 5 | 22 |
| 240 | Office | 52 | 10 | 4 | 27 |
| 241 | Office | 52 | 10 | 4 | 19 |
| 242 | Office | 52 | 10 | 4 | 18 |
| 243 | Student Orgs | 352 | 12 | 7 | 24 |
| 244 | Student Orgs | 352 | 12 | 7 | 31 |
| 245 | Student Orgs | 352 | 12 | 7 | 20 |
| 247 | Conference | 200 | 12 | 5 | 35 |
| 248 | Office | 52 | 10 | 4 | 25 |
| 248 | Office | 52 | 10 | 4 | 15 |
| 253 | Safe Room | 52 | 10 | 4 | 12 |
| 254 | Office | 52 | 10 | 4 | 12 |
| 255 | Office | 52 | 10 | 4 | 12 |
| 256 | Womens Center | 150 | 10 | 5 | 12 |
| 257 | Office | 78 | 10 | 4 | 18 |
| 258 | Office | 78 | 10 | 4 | 20 |
| 259 | Office | 78 | 10 | 4 | 16 |
| 260 | Resource Area | 120 | 10 | 5 | 19 |
| 261 | Student Orgs | 120 | 10 | 5 | 21 |
| 262 | Office | 78 | 10 | 4 | 19 |
| 263 | Office | 78 | 10 | 4 | 19 |
| 264 | Office | 78 | 10 | 4 | 19 |
| 266 | Paint | 52 | 10 | 4 | 15 |

**Table 19 – Redesign Sheet Metal Ductwork Takeoff**

| Redesign Sheet Metal Ductwork Takeoff (Second Floor East) | | | | | |
|---|---|---|---|---|---|
| Large Dim | Small Dim | Length (lnft) | Gage Number | Pounds/SF | Pounds of SM |
| 10 | 4 | 266 | 24 | 0.975 | 605 |
| 10 | 5 | 176 | 24 | 0.975 | 429 |
| 12 | 5 | 103 | 24 | 0.975 | 285 |
| 12 | 7 | 75 | 24 | 0.975 | 232 |
| 12 | 3.14 | 16 | 24 | 0.975 | 49 |
| 14 | 3.14 | 44 | 24 | 0.975 | 157 |
| 16 | 3.14 | 42 | 22 | 1.22 | 215 |
| 18 | 3.14 | 25 | 22 | 1.22 | 144 |
| 20 | 3.14 | 70 | 22 | 1.22 | 447 |
| 24 | 3.14 | 35 | 22 | 1.22 | 268 |
| | | | | Total | 2830 |

The table below shows the ratio between redesign and existing from the tables above being applied to all the spaces being replaced with the dedicated outdoor air system with chilled beams. A detailed ductwork takeoff of the existing design being replaced can be found in Appendix B at the end of the report.

**Table 20 – Existing vs. Redesign Ductwork**

| Sheet Metal in Ductwork | | | | |
|---|---|---|---|---|
| | Supply | Return | Cost/lb | Total Cost |
| Existing (lbs) | 25474 | 18354 | 8.99 | $394,018.08 |
| Redesign (lbs) | 19458 | 14019 | 8.99 | $300,960.42 |
| Pounds Saved | 6016 | 4335 | Total Saved | $93,057.66 |

The ratio calculated between the existing and redesign supply ductwork runs was also used to estimate the sheet metal reduction of the return ductwork in the redesign. The following table shows a cost comparison between the existing and redesign on a first cost basis.

**Table 21 – Existing vs. Redesign Initial Cost Comparison**

| Existing Total of Takeoffs | | Redesign Total Takeoffs | |
|---|---|---|---|
| VAV Boxes | $110,081.00 | Chilled Beams | $378,678.00 |
| Air Handlers | $515,000.00 | Piping | $144,664.60 |
| Diffusers | $17,152.30 | Air Handlers | $209,000.00 |
| Sheet Metal | $394,018.08 | Sheet Metal | $300,960.42 |
| | | CW Pumps | $20,822.00 |
| | | CW Heat Exchangers | $24,061.60 |
| Total | $1,036,251.38 | Total | $1,078,186.62 |

The new system will be estimated to cost roughly $42,000 more than the existing design. The major savings in the redesign come from the reduction in air handling units; however, the initial cost of the chilled beams offset the savings. The chilled beam cost estimate is a ballpark estimate that was found by contacting a sales representative. The piping redesign estimate was found by finding the amount of piping running to the existing VAV boxes located in each individual space. Once that value was found, it was double to account for both the heating and cooling loops to the chilled beams.

After conducting a first cost comparison, an evaluation of the energy savings from the redesign was done to calculate the simple payback period. The information below was determined after analyzing the results obtained from the TRACE 700 energy model simulated over the course of a year for the SRU Student Union and applying the utility rates for the area.

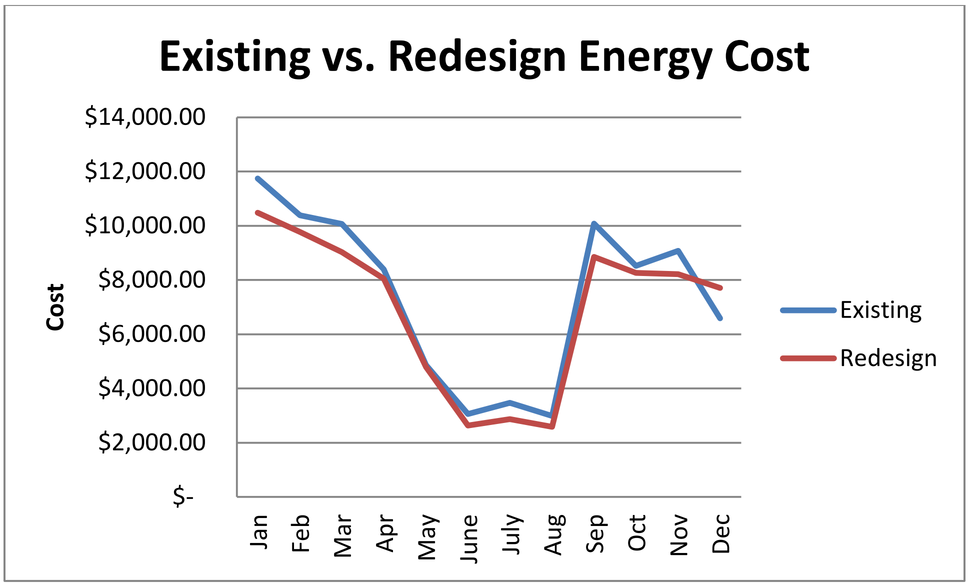



**Figure 33 – Existing vs. Redesign Energy Cost Comparison**

**Table 22 – Existing vs. Redesign Annual Energy Cost Comparison**

| Redesign Annual Energy Cost | | | | |
|---|---|---|---|---|
| Natural Gas ($) | Electricity ($) | Steam ($) | Water ($) | Total |
| 12067.58 | 63629.73 | 5135.97 | 2425.05 | 83258.33 |
| **Existing Annual Energy Cost** | | | | |
| Natural Gas ($) | Electricity ($) | Steam ($) | Water ($) | Total ($) |
| 8712.60 | 67894.99 | 12636.45 | 0.00 | 89244.04 |

Based on the amount of energy saved each year in the system redesign, a simple payback period was conducted. The active chilled beams require virtually no maintenance, adding to the positive attributes of using such equipment and decreasing the payback period. Table 23 shows the time it takes for the energy savings to pay for the additional first costs of the redesign.

Table 23 – DOAS with Chilled Beams Payback Table

| Chilled Beams Simple Payback Period | | | | |
|---|---|---|---|---|
| Year | C.B. Additional Cost | Maitenance | Utility Savings | Total |
| 0 | ($41,934.88) | | | ($41,934.88) |
| 1 | | | $5,985.71 | ($35,949.17) |
| 2 | | | $11,971.42 | ($29,963.46) |
| 3 | | | $17,957.13 | ($23,977.75) |
| 4 | | $150.00 | $23,942.84 | ($17,992.04) |
| 5 | | | $29,928.55 | ($12,006.33) |
| 6 | | | $35,914.26 | ($6,020.62) |
| 7 | | | $41,899.97 | ($34.91) |
| 8 | | $150.00 | $47,885.68 | $5,950.80 |
| 9 | | | $53,871.39 | $11,936.51 |
| 10 | | | $59,857.10 | $17,922.22 |
| 11 | | | $65,842.81 | $23,907.93 |
| 12 | | $150.00 | $71,828.52 | $29,893.64 |
| 13 | | | $77,814.23 | $35,879.35 |
| 14 | | | $83,799.94 | $41,865.06 |
| 15 | | | $89,785.65 | $47,850.77 |
| 16 | | $150.00 | $95,771.36 | $53,836.48 |
| 17 | | | $101,757.07 | $59,822.19 |
| 18 | | | $107,742.78 | $65,807.90 |
| 19 | | | $113,728.49 | $71,793.61 |
| 20 | | $150.00 | $119,714.20 | $77,779.32 |

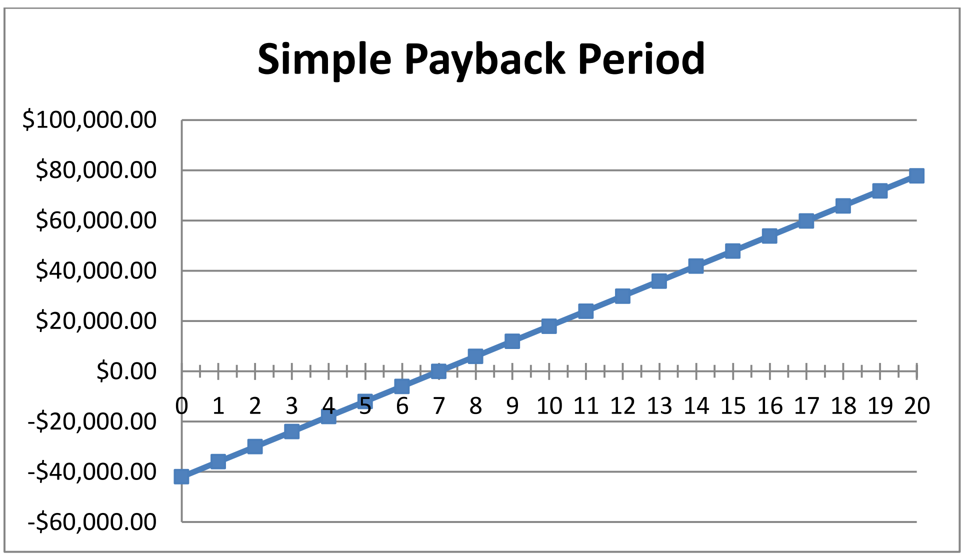



Figure 34 – Existing vs. Redesign Annual Energy Cost Comparison

Based off the calculations above, the dedicated outdoor air system with active chilled beams will be paid off at the turn of the 7th year in operation.

## 6.4 Recommendations and Conclusions

Based on the assumptions and conclusions made above, replacing a portion of the building with a dedicated outdoor air system with chilled beams is a reasonable consideration. Although the new system has an increased initial cost, the money saved in energy quickly pays for the additional first costs. The building will still maintain LEED Status with the redesign and additional energy savings, however the redesign will only be awarded an additional point and will not be able to step up to LEED Gold. The redesign is also feasible because the main objective is to provide occupant comfort and control while incorporating sustainability and green design. This redesign ensures both requirements are integrated into the new system design.

# 7.0 Solar Thermal Water Heating System – Mechanical Depth

## 7.1 Introduction

The purpose of this study is to implement a solar thermal water heating system and to explore the benefits and feasibility, if any, of such a system in the SRU Student Union. The building requires roughly 10,000 gallons of hot water for domestic use each day. The new system will be designed to assist in heating the water rather than a sole source of domestic hot water.

## 7.2 Solar Thermal Water Heating System Design

The system design was created through determining the amount of hot water that can be produced based on the available area on the roof of the first floor. An initial design issue is the space available for the solar collectors. The ideal orientation of a solar collector is facing due south at a tilt within plus or minus 5 degrees of the latitude. For the SRU Student Union, the collectors will be on the southern facing portion of the roof with a tilt of 45 degrees. This positioning will maximize the solar collection throughout the day and year. Below is a model of where the collectors will be placed on the building based on the information presented above.

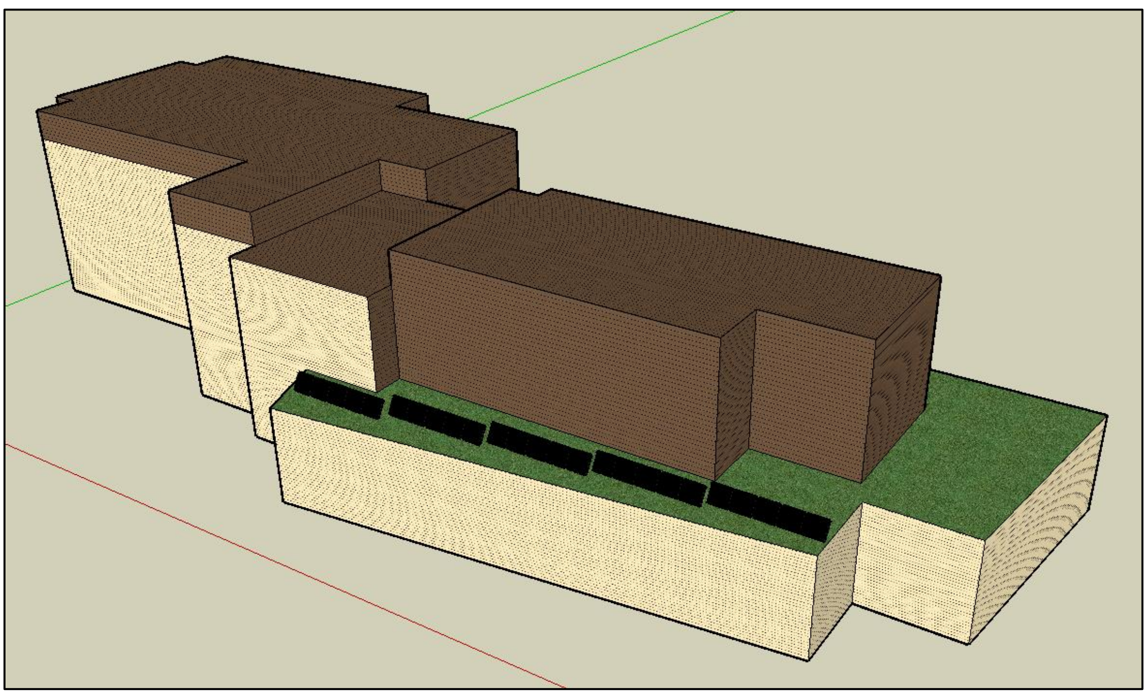


**Figure 35 – SRU Student Union Model with Solar Collectors**

After selecting the location and orientation of the collectors, monthly insolation days were found based off the location of the building in order to calculate the amount of energy the collectors can produce throughout the year. The energy outputs in the table below were found by using specific performance data from Apricus model AP-30. Based on the area of the collectors and insolation, the following monthly energy outputs were found and converted to therms in order to find the amount of money saved in purchased steam. The energy output is also based in a change in temperature of 100 ºF.

**Table 24 – Solar Collector Energy Output and Annual Cost Savings**

| Solar Thermal Domestic Hot Water Heating Output | | | | | |
|---|---|---|---|---|---|
| Month | Insolation (kWh/m$^2$/day) | Absorber Area (m$^2$) | Energy Output (kWh) | Therms | Cost ($) |
| Jan | 1.69 | 60 | 2129 | 72.7 | 83.67 |
| Feb | 2.47 | 60 | 3112 | 106.2 | 122.30 |
| March | 3.31 | 60 | 4171 | 142.4 | 163.92 |
| April | 4.4 | 60 | 5544 | 189.2 | 217.88 |
| May | 5.06 | 60 | 6376 | 217.6 | 250.58 |
| June | 5.68 | 60 | 7157 | 244.3 | 281.27 |
| July | 5.57 | 60 | 7018 | 239.5 | 275.81 |
| Aug | 4.96 | 60 | 6250 | 213.3 | 245.63 |
| Sept | 4.04 | 60 | 5090 | 173.7 | 200.04 |
| Oct | 2.86 | 60 | 3604 | 123.0 | 141.64 |
| Nov | 1.77 | 60 | 2230 | 76.1 | 87.64 |
| Dec | 1.44 | 60 | 1814 | 61.9 | 71.29 |
| | | | | Total | 2141.65 |

The primary means of heating the domestic hot water is done by using steam from the campus steam plant with an auxiliary natural gas backup system. The water heated by the solar collectors will be used to preheat the incoming water supply before being heated to the proper temperature from the campus steam. The schematic below shows the process where an internal heat exchanger transfers the heat from the solar collectors and campus steam to the water that will be used for the domestic hot water supply of the building.

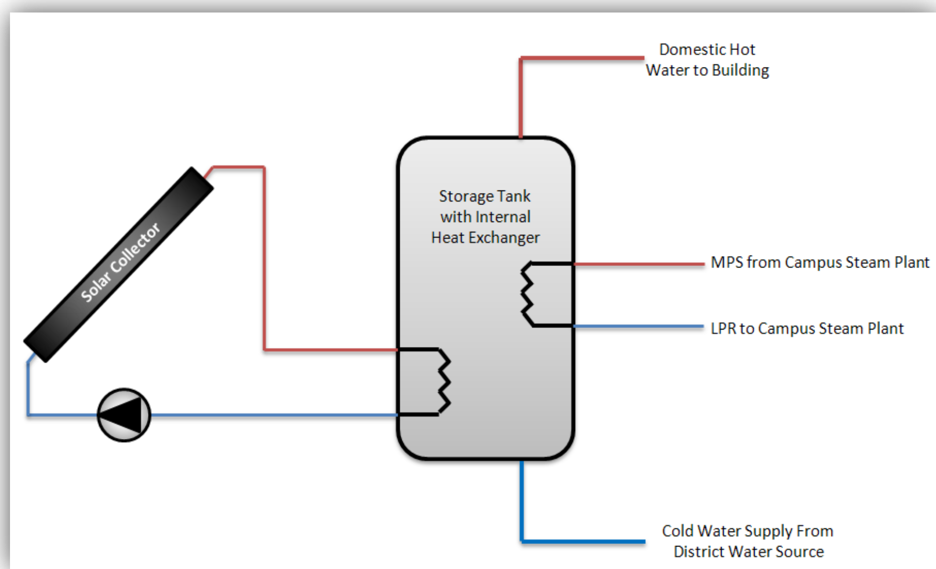
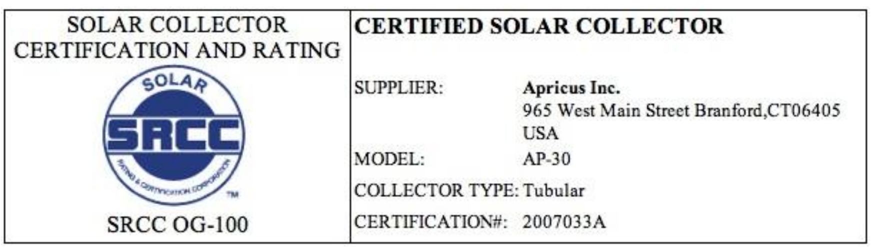



**Figure 36 – Solar Collector Schematic**

After the total annual output was found, a simple payback period study was conducted to determine the feasibility of the system. Due to the nature of the technology, several federal and state government incentives may apply to the design. After research, the design can potentially be awarded two government incentives to help cover the initial costs of the system. An important assumption made in researching incentives is the building will be treated as commercial due to the office space and retail that accounts for over 50% of the occupied spaces.

The first incentive is the Pennsylvania Sunshine Solar Rebate Program. This incentive can be applied to solar water heat used for domestic hot water. The amount rewarded to a solar thermal system is 35% of the installed costs of the system.

The second incentive is Federal Government issue under the Business Energy Investment Tax Credit. The tax credit applies for an amount of 30% of the initial cost of the solar system. The solar collectors must meet the requirements of the Solar Rating and Certification Corporation according to the standard Operation Guidelines for Certifying Solar Collectors (SRCC OG-100). Below is a section from the AP-30 collector specifications that demonstrates compliance.


SOLAR COLLECTOR CERTIFICATION AND RATING

SRCC OG-100

**CERTIFIED SOLAR COLLECTOR**

SUPPLIER: **Apricus Inc.**
965 West Main Street Branford,CT06405
USA

MODEL: AP-30

COLLECTOR TYPE: Tubular

CERTIFICATION#: 2007033A

**Figure 37 – Solar Collector Payback Table with Government Incentives**

Both RS Means and cost estimates from the vender were used to find a ballpark initial cost estimate per collector. The collector itself will cost $2,300.00 for a 30 tube array with an additional installation cost of $1124.40 per array. The SRU Student Union design uses 25 arrays for a total cost of $85,610.00. Due to the high initial costs, implementing such a system is not economically feasible unless the government incentives can be applied. Without the incentives, the systems lifespan will run out before the time it takes to receive the payback from the energy savings. The table below shows a simple payback period assuming the building will be granted the government incentives.

If the portion of the green roof is removed, this too offsets the additional costs of the solar collector system. The following table provides a detailed cost breakdown from removing 3000 square feet of the green roof where the solar collectors will be placed.

Table 25 – Green Roof Section Takeoff

| Green Roof Takeoff | | | |
|---|---|---|---|
| Green Roof Systems | Cost/SF | Square Footage | Cost |
| Plant Medium | $10.00 | 3000 | $30,000.00 |
| Protection Board | $1.50 | 3000 | $4,500.00 |
| Filter Fabric | $0.75 | 3000 | $2,250.00 |
| Waterproofing | $1.60 | 3000 | $4,800.00 |
| Drainage Board | $1.25 | 3000 | $3,750.00 |
| | | System Total | $45,300.00 |

Table 26 – Solar Collector Payback Table without Government Incentives

| Solar Water Collector Payback Period Without Incentives | | | | |
|---|---|---|---|---|
| Year | Cost of Solar Thermal | Utility Savings | Green Roof Savings | Total |
| 0 | ($85,610.00) | | $45,300.00 | ($40,310.00) |
| 1 | | $2,141.65 | | ($38,168.35) |
| 2 | | $4,283.30 | | ($36,026.70) |
| 3 | | $6,424.95 | | ($33,885.05) |
| 4 | | $8,566.60 | | ($31,743.40) |
| 5 | | $10,708.25 | | ($29,601.75) |
| 6 | | $12,849.90 | | ($27,460.10) |
| 7 | | $14,991.55 | | ($25,318.45) |
| 8 | | $17,133.20 | | ($23,176.80) |
| 9 | | $19,274.85 | | ($21,035.15) |
| 10 | | $21,416.50 | | ($18,893.50) |
| 11 | | $23,558.15 | | ($16,751.85) |
| 12 | | $25,699.80 | | ($14,610.20) |
| 13 | | $27,841.45 | | ($12,468.55) |
| 14 | | $29,983.10 | | ($10,326.90) |
| 15 | | $32,124.75 | | ($8,185.25) |
| 16 | | $34,266.40 | | ($6,043.60) |
| 17 | | $36,408.05 | | ($3,901.95) |
| 18 | | $38,549.70 | | ($1,760.30) |
| 19 | | $40,691.35 | | $381.35 |
| 20 | | $42,833.00 | | $2,523.00 |

As shown in the table above, the graph below illustrates a visual representation of the information calculated. The system will be paid for by the 19th year of operation according to the estimated collector energy performance.

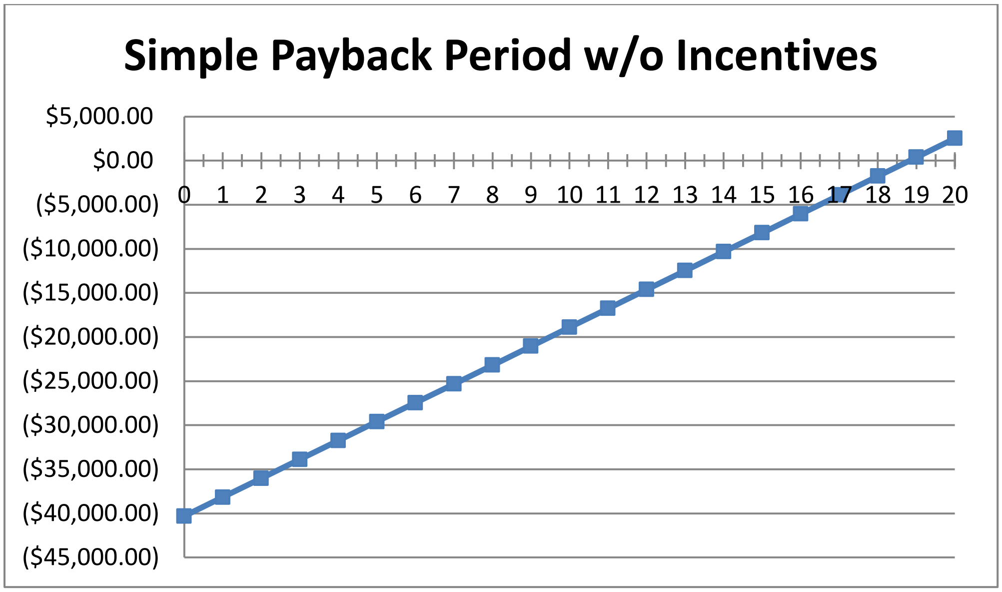



**Figure 38 – Solar Collector Simple Payback Graph**

**Table 27 – Solar Collector Cost Table with Government Incentives**

| Cost Breakdown | |
|---|---|
| Solar Collector Cost | ($85,610.00) |
| Incentive | $29,963.50 |
| Tax Credit | $25,683.00 |
| Green Roof Savings | $45,300.00 |
| Net Savings | $15,336.50 |

## 7.3 Conclusions and Recommendations

Based on the information provided above, it is difficult to determine whether or not using solar thermal water collectors is worthwhile. Removing the portion of the green roof could potentially cause issues with the space below due to the insulation properties the green roof provides, although the space beneath is an entry vestibule and circulation space. Another issue to consider is the aesthetics that go along with the addition of the solar thermal collectors. The collectors potentially obstruct the views from several offices and meeting rooms located on the second floor. The solar collectors have negligible structural complications and will be less weight when compared to the green roof. With further consideration, the benefits of adding this system don't seem to be overcome the consequences. Without any government incentives, the system should not be considered feasible based on the payback period and additional design and architectural complications.

# 8.0 Structural Breadth Study

## 8.1 Design Objectives

The objective of the structural breadth is to change the existing composite steel decking floor system to prefabricated hollow core planks. The evaluation will also explore the effects of doing so by resizing existing girders in order to hold the new loads created by the precast floor planks.

## 8.2 Assumptions and Design Strategies

Several assumptions were made during the analysis in order to accurately evaluate the floor system. The precast hollow core slabs will use a 2 inch topping to ensure a rigid diaphragm and to avoid further structural complications. The ceiling to floor heights have been designed to remain within ½ inch of the existing depths to decrease potential issues within the other building trades.

The beam and girder orientation has been reversed in order to allow the precast hollow core slabs to carry loads resulting in using fewer beams. Although the orientation has been switched, the girder depths were sized equal to the existing beam depths in order to allow the ductwork servicing the dining and kitchen below to remain unchanged. The redesign is based off a portion of the second floor bearing the weight of the ballroom. This section was selected due to the simple and typical bay design. Due to the nature of the building, few areas of the building have a typical bay layout.

## 8.3 Floor Slab System Redesign

Superimposed Dead Load – 15 psf
Dead Load – 15 psf
Live Load (ballroom) – 100 psf

Total Loads – 130 psf

Prestressed Concrete
8"x4'-0" Hollow Core Plank

1 Hour Fire Resistance Rating With 2" Topping

PHYSICAL PROPERTIES
Composite Section

| | |
|---|---|
| $A_c$ = 301 in.$^2$ | Precast $b_w$ = 13.13 in. |
| $I_c$ = 3134 in.$^4$ | Precast $S_{bcp}$ = 616 in.$^3$ |
| $Y_{bcp}$ = 5.09 in. | Topping $S_{tct}$ = 902 in.$^3$ |
| $Y_{tcp}$ = 2.91 in. | Precast $S_{tcp}$ = 1076 in.$^3$ |
| $Y_{tct}$ = 4.91 in. | Precast Wt. = 245 PLF |
| | Precast Wt. = 61.25 PSF |

SAFE SUPERIMPOSED SERVICE LOADS — IBC 2006 & ACI 318-05 (1.2 D + 1.6 L)

| Strand Pattern | | SPAN (FEET) | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 | 26 | 27 | 28 | 29 | 30 | 31 | 32 | 33 | 34 | 35 |
| 4 - 1/2"ø | LOAD (PSF) | 280 | 256 | 226 | 199 | 190 | 170 | 151 | 137 | 119 | 106 | 93 | 82 | 72 | | | | | | |
| 6 - 1/2"ø | LOAD (PSF) | 366 | 341 | 318 | 299 | 271 | 245 | 223 | 211 | 196 | 176 | 159 | 143 | 129 | 113 | 98 | 85 | 74 | 63 | 53 |
| 7 - 1/2"ø | LOAD (PSF) | 367 | 342 | 320 | 300 | 282 | 265 | 243 | 221 | 202 | 189 | 180 | 165 | 151 | 134 | 118 | 104 | 91 | 80 | 69 |

**Figure 39 – Prestressed Hollow Core Plank Selection**

The prestressed concrete plank was selected based off the Nitter House specifications for 8" Hollow Core Plank with 2" Topping after calculating the capacity needed to carry the loads from the ballroom. The hollow core plank will be replacing the following 4 ½" normal weight concrete with 3" composite steel deck.

FLOOR SCHEDULE

| MARK | TYPE | REINFORCING | TOTAL THICKNESS |
|---|---|---|---|
| S1 | 3 1/2" NW CONC. SLAB ON GALV. 2"- 20GA. COMP. STEEL DECK | REINF. W/ 6X6-W1.4XW1.4 W.W.F. | 5 1/2" |
| S2 | 3 1/2" NW CONC. SLAB ON 2"-20 GA. COMP. STEEL DECK | REINF. W/ 6X6-W2.1XW2.1 W.W.F. & #3 @ 12" O.C. OVER GIRDERS | 5 1/2" |
| S3 | 4 1/2" NW CONC. SLAB ON 3"-20 GA. COMP. STEEL DECK | REINF. W/ 6X6-W2.1XW2.1 W.W.F. | 7 1/2" |

**Figure 40 – Existing Composite Steel Decking and Concrete**

## 8.4 Girder Redesign

### 8.4.1 Sizing Girder

$W_{TL} = 1.2D + 1.6L$

Superimposed Dead Load – 15 psf

Weight of Prestressed Plank – 86.25 psf

$W_{TL} = 1.2( 15 + 86.25 ) + 1.6( 100 ) = 281.5$ psf

$M_U = ( 281.5 )( 26 )( 24 )^2 / 8 = 527$ ft*kip

From the Steel Construction Manual – W18X71 @ 548 psf capacity

$M_U$ = [ ( 281.5 )( 26 ) + 71 ] ( 24 )$^2$/ 8 = 532.1 ft-kip < 548 ft-kip therefore W18X71 is OK

### 8.4.2 Live Load Deflection

$\Delta_{LL}$ = 5 $W_{LL}$ $L^4$ ( 1728) / ( 384 E I )

E = 29,000,000 psi

$I_{W18X71}$= 1170 in$^4$

$\Delta_{LL}$ = 5 (100*4) 24$^4$ ( 1728) / ( 384 * 29000000 * 1170 ) = 0.088 inches

Allowable Live Load Deflection:

$\Delta_{LL}$ = L / 360 = ( 24 ft * 12 in/ft ) / 360 = 0.80 inches

0.60 inches < 0.80 inches therefore OK

### 8.4.3 Total Load Deflection

$\Delta_{TL}$ = 5 $W_{TL}$ $L^4$ ( 1728) / ( 384 E I )

E 29,000,000 psi

$I_{W18X71}$= 1170 in$^4$

$\Delta_{TL}$ = 5 (130*4) 24$^4$ ( 1728) / ( 384 * 29000000 * 1170 ) = 0.12 inches

Allowable Total Load Deflection:

$\Delta_{TL}$ = L / 240 = ( 24 ft * 12 in/ft ) / 240 = 1.2 inches

0.12 inches < 1.2 inches therefore OK

A table with the calculations presented above can be found and verified at the end of the report in Appendix E.

### 8.4.4 Existing Beam and Girder Design

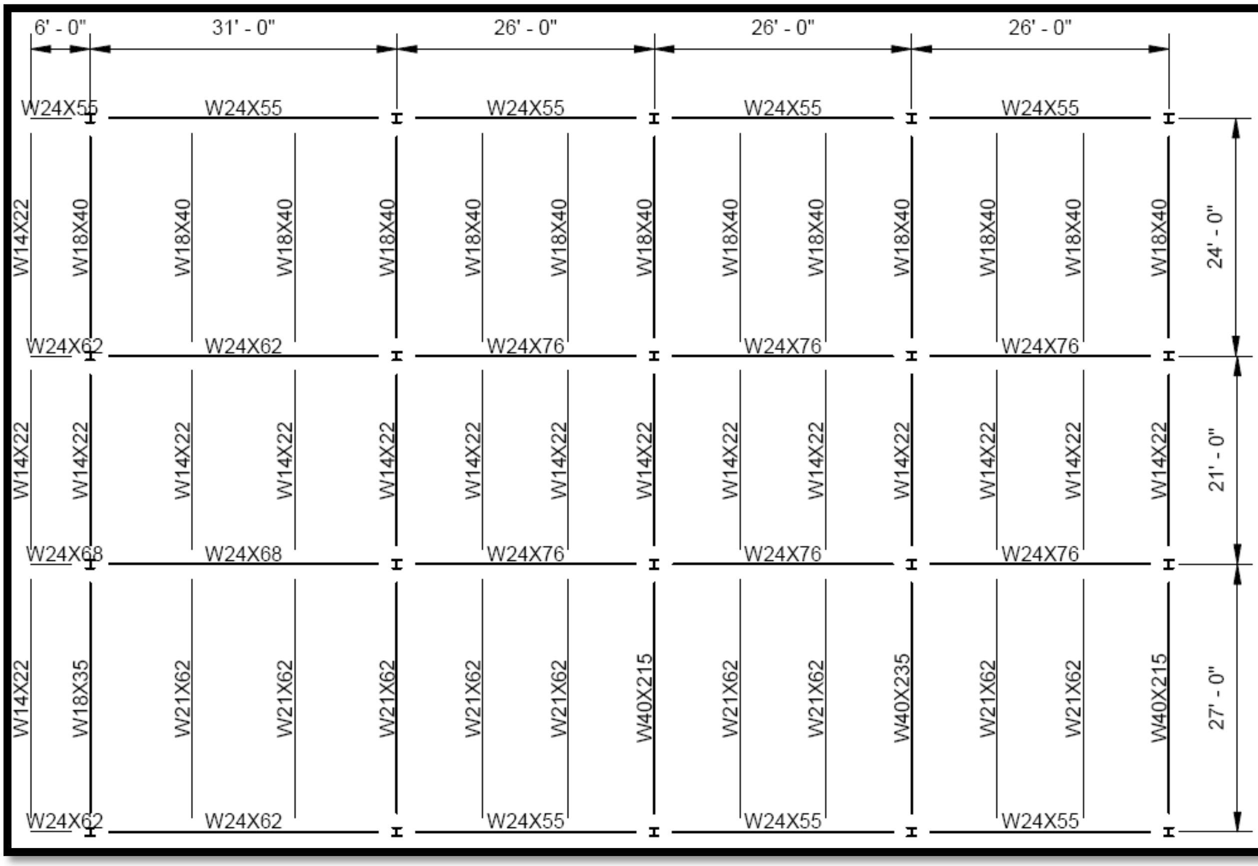



**Figure 41 – Existing Steel Beam and Girder Design**

### 8.4.5 Beam and Girder Redesign

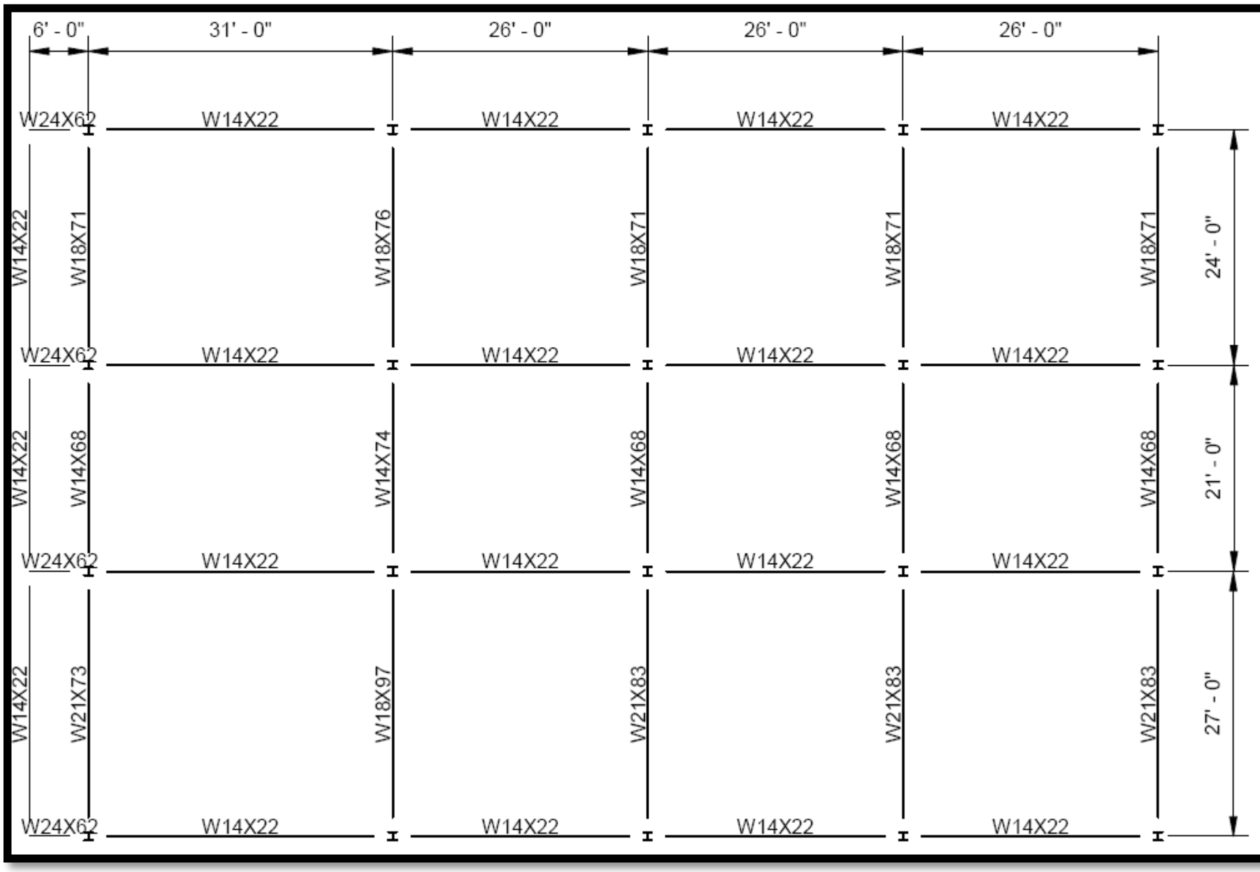



**Figure 42 – Steel Beam and Girder Redesign**

## 8.5 Recommendations and Conclusions

Overall, the redesign appears to save a considerable amount of steel and time spent on installation. However, applying precast hollow core planks to the entire building would be much more difficult. The precast planks were only assigned to this portion of the building due to the simple and somewhat consistently sized bays of the structure. If precast hollow core planks were to be used throughout the entire building, careful planning and coordination would become a more prevalent issue to minimize additional construction complications.

# 9.0 Construction Breadth Study

## 9.1 Objectives

The construction breadth will explore techniques to accelerate construction along with ways to reduce initial cost throughout the building. This breadth couples with the structural breadth such that the precast hollow core slabs will hope to decrease construction time and the cost of steel used in the framing. It is also incorporated into the mechanical breadth by evaluating the effects of using less sheet metal evaluated previously in the report. The following report will describe techniques used to conduct the analysis and obtain results.

## 9.2 Assumptions and Redesign Methods

The schedule acceleration was determined based off ratios of the amount of material saved through the redesign along with construction and erection times provided through material vendors.

The existing cost analysis was conducted from information off a base bid provided by the architect and engineers. Steel beam and girder takeoffs were done to accurately estimate the steel in the selected section. From the base bid, 10 percent of the total weight of the beam and girders is needed for steel connections. This ratio was also used in the framing redesign.

Several different methods were used in order to accurately estimate the cost of the new structural system. The prestressed hollow core planks were first sized to handle the assumed loads and were then priced for cost per square foot by Nitter House based on plank thickness. The general contractor provided a cost estimate for the 2" topping needed for the precast planks. After resizing the beam and girder frame, the amount of steel (in tons) of the beams and girders was determined based off the self-weight of each member. The weight of connections needed was estimated based off the ratio determined for connections per ton of steel from the existing framing.

## 9.3 Schedule Acceleration

| | Task Name | Duration | Start | Finish |
|---|---|---|---|---|
| 1 | EXISTING SCHEDULE | | | |
| 2 | GENERAL CONSTRUCTION | | | |
| 3 | Erect West Steel | 14 days | Wed 12/15/10 | Mon 1/3/11 |
| 4 | Deck and Detail West Steel | 20 days | Wed 12/29/10 | Tue 1/25/11 |
| 5 | West Slab on Deck | 10 days | Wed 1/26/11 | Tue 2/8/11 |
| 6 | | | | |
| 7 | HVAC CONSTRUCTION | | | |
| 8 | Install HVAC Piping Levels 1-3 | 60 days | Fri 2/25/11 | Thu 5/19/11 |
| 9 | Install HVAC Equipment Roof | 50 days | Fri 3/18/11 | Thu 5/26/11 |
| 10 | Install Ductwork Levels 1-3 | 60 days | Fri 3/25/11 | Thu 6/16/11 |
| 11 | Install HVAC Branch Piping 1-3 | 45 days | Fri 5/13/11 | Thu 7/14/11 |
| 12 | Install Branch Ductwork 1-3 | 25 days | Fri 5/13/11 | Thu 6/16/11 |
| 13 | | | | |
| 14 | | | | |
| 15 | REDESIGN SCHEDULE | | | |
| 16 | GENERAL CONSTRUCTION | | | |
| 17 | Erect West Steel | 10 days | Wed 12/15/10 | Tue 12/28/10 |
| 18 | Deck and Detail West Steel | 15 days | Wed 12/29/10 | Tue 1/18/11 |
| 19 | Plank Erection and Grouting | 4 days | Wed 12/29/10 | Mon 1/3/11 |
| 20 | West Slab on Deck | 7 days | Wed 1/19/11 | Thu 1/27/11 |
| 21 | | | | |
| 22 | HVAC CONSTRUCTION | | | |
| 23 | Install HVAC Piping Levels 1-3 | 70 days | Fri 2/25/11 | Thu 6/2/11 |
| 24 | Install HVAC Equipment Roof | 40 days | Fri 3/18/11 | Thu 5/12/11 |
| 25 | Install Ductwork Levels 1-3 | 45 days | Fri 3/25/11 | Thu 5/26/11 |
| 26 | Install Branch Ductwork 1-3 | 19 days | Thu 4/28/11 | Tue 5/24/11 |
| 27 | Install HVAC Branch Piping 1-3 | 55 days | Fri 5/13/11 | Thu 7/28/11 |

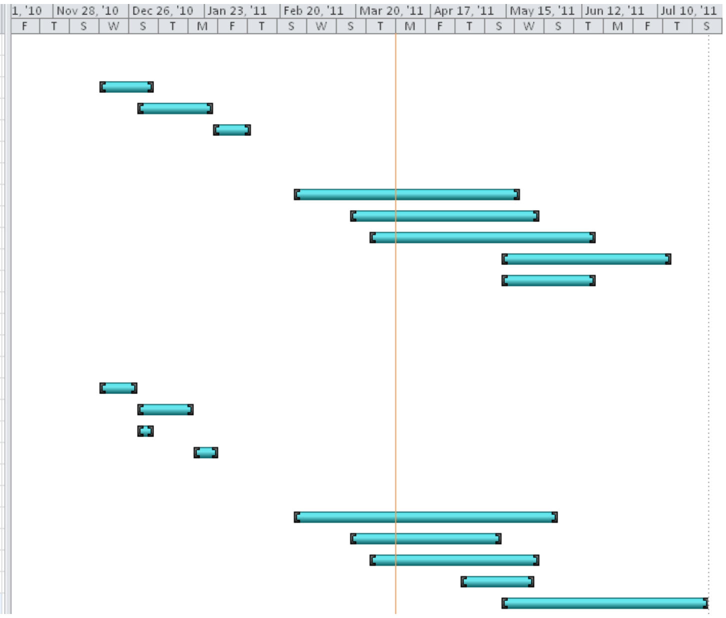



**Figure 43 – Existing vs. Redesign Schedules**

Based on the schedule above, the precast hollow core planks will accelerate construction time. The accelerated construction of the precast planks saves construction time by over a full week of work. However, the mechanical redesign additional piping runs that will be running to and from the chilled beams will add a considerable amount of time to the schedule. The reduction in ductwork installation does not overcome the time needed to install the piping.

## 9.4 Overall Cost Analysis of Existing vs. Redesign

### 9.4.1Existing Cost Analysis

| Composite Deck and Steel Beam Takeoffs and Cost Analysis (Ballroom) | | | | |
|---|---|---|---|---|
| Existing Steel Beams | | | | |
| Beam Tag | Number of Beams | Length (ft) | lb/ft | lbs |
| W24X76 | 6 | 26 | 76 | 11856 |
| W24X55 | 6 | 26 | 55 | 8580 |
| W24X55 | 1 | 31 | 55 | 1705 |
| W24X62 | 2 | 31 | 62 | 3844 |
| W24X68 | 1 | 31 | 68 | 2108 |
| W18X40 | 13 | 24 | 40 | 12480 |
| W14X22 | 14 | 21 | 22 | 6468 |
| W21X62 | 9 | 27 | 62 | 15066 |
| W14X22 | 1 | 27 | 22 | 594 |
| W18X35 | 1 | 27 | 35 | 945 |
| W40X215 | 2 | 27 | 215 | 11610 |
| W40X235 | 1 | 27 | 235 | 6345 |
| W14X22 | 1 | 24 | 22 | 528 |
| W24X62 | 2 | 6 | 62 | 744 |
| W24X55 | 1 | 6 | 55 | 330 |
| W24X68 | 1 | 6 | 68 | 408 |
| Totals | 62 | | | 83611 |
| | Pounds of Steel Beams | Tons of Steel | $/ton | Total Cost $ |
| | 83611 | 41.81 | 3250.00 | 135867.88 |
| | Steel Connections Ratio | Tons of Steel | $/ton | Total Cost $ |
| | 41.27/158=x/15.8 | 4.18 | 3250.00 | 13585.00 |
| | | | | Steel Total $ |
| | | | | 149452.88 |
| | Metal Decking | | | |
| | Material | SF | $/sf | Total Cost $ |
| | 3" Metal Deck | 8318 | 2.50 | 20795.00 |
| | Concrete Slab on Deck | | | |
| | Material | Area sf | $/sf | Concrete Cost |
| | 4.5" topping | 8318 | 8.50 | 70703.00 |
| | | | | Total Cost |
| | | | | 240950.88 |

### 9.4.2 Redesign Cost Analysis

| Redesign Precast Planks and Steel Beam Cost Analysis (Ballroom) | | | | |
|---|---|---|---|---|
| Steel Beam Redesign | | | | |
| Tag | Number of Beams | Length (ft) | lb/ft | lbs |
| Girders | | | | |
| W14X22 | 1 | 27 | 22 | 594 |
| W14X22 | 1 | 21 | 22 | 462 |
| W14X22 | 1 | 24 | 22 | 528 |
| W21X83 | 4 | 27 | 83 | 8964 |
| W14X68 | 4 | 21 | 68 | 5712 |
| W18X71 | 4 | 24 | 71 | 6816 |
| W14X74 | 1 | 21 | 74 | 1554 |
| W18X76 | 1 | 24 | 76 | 1824 |
| W18X97 | 1 | 27 | 97 | 2619 |
| W24X62 | 4 | 6 | 62 | 1488 |
| Const. Bracing | | | | |
| W14X22 | 4 | 31 | 22 | 2728 |
| W14X22 | 12 | 26 | 22 | 6864 |
| Totals | 38 | | | 40153 |
| | Pounds of Steel Beams | Tons of Steel | $/ton | Total Cost $ |
| | 40153 | 20.08 | 3250.00 | 65248.63 |
| | Steel Connections Ratio | Tons of Steel | $/ton | Total Cost $ |
| | 20.08/158 = x/15.8 | 2.01 | 3250.00 | 6532.50 |
| | | | | Steel Total $ |
| | | | | 71781.13 |
| | Precast Hollow Core Plank Redesign | | | |
| | Plank Thickness | Area sf | $/sf | Plank Cost $ |
| | 8" Planks | 5616 | 7.50 | 42120.00 |
| | 10" Planks | 2702 | 8.50 | 22967.00 |
| | | 8318 | | 65087.00 |
| | Concrete Topping | | | |
| | Material | Area sf | $/sf | Topping Cost $ |
| | 2" Topping | 8318 | 2.50 | 20795.00 |
| | | | | Total Cost $ |
| | | | | 157663.13 |

## 9.5 Conclusions

Based on the structural redesign, both the construction time and costs are reduced. The construction is decreased by 10 days and saves a total of $83,287.75. Although the reductions are minimal, the implementation of precast hollow core planks seems to be a reasonable redesign consideration. The increased mechanical time is a result of increased piping runs throughout the building, however the overall mechanical performance had a considerable increase in efficiency.

# 10.0 Credits and Acknowledgements

I would like to express my gratitude all of the people who have helped me with my thesis throughout the course of the year.  Special thanks go out to the following for all their assistance:

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- Ron Grimm (DRS Architects)

I would also like to thank my friends in the AE program with me along with those who have already graduated.  It couldn't have been done without you!

# 11.0 List of Figures and Tables

# Appendix A – Energy Consumption and Cost Tables

| Chilled Beams - On Peak Monthly Electricity Energy Consumption Cost Analysis | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Electrcity | | Price per kWh | | Price per kW | | Monthly Cost ($) | | Total Monthly Cost ($) |
| Month | Consumption (kWh) | Demand (kW) | 0 - 40,000 kW | > 40,000 kW | 0 - 100 kW | > 100 kW | Consumption | Demand | |
| Jan | 106988 | 289 | 0.05113 | 0.04615 | 7.04 | 6.05 | 5136.70 | 1847.45 | 6984.15 |
| Feb | 95264 | 316 | 0.05113 | 0.04615 | 7.04 | 6.05 | 4595.63 | 2010.80 | 6606.43 |
| Mar | 105418 | 289 | 0.05113 | 0.04615 | 7.04 | 6.05 | 5064.24 | 1847.45 | 6911.69 |
| Apr | 101332 | 316 | 0.05113 | 0.04615 | 7.04 | 6.05 | 4875.67 | 2010.80 | 6886.47 |
| May | 50791 | 197 | 0.05113 | 0.04615 | 7.04 | 6.05 | 2543.20 | 1290.85 | 3834.05 |
| June | 19644 | 166 | 0.05113 | 0.04615 | 7.04 | 6.05 | 1105.77 | 1103.30 | 2209.07 |
| July | 23282 | 167 | 0.05113 | 0.04615 | 7.04 | 6.05 | 1273.66 | 1109.35 | 2383.01 |
| Aug | 19270 | 162 | 0.05113 | 0.04615 | 7.04 | 6.05 | 1088.51 | 1079.10 | 2167.61 |
| Sep | 109510 | 376 | 0.05113 | 0.04615 | 7.04 | 6.05 | 5253.09 | 2373.80 | 7626.89 |
| Oct | 104868 | 320 | 0.05113 | 0.04615 | 7.04 | 6.05 | 5038.86 | 2035.00 | 7073.86 |
| Nov | 100265 | 295 | 0.05113 | 0.04615 | 7.04 | 6.05 | 4826.43 | 1883.75 | 6710.18 |
| Dec | 54657 | 234 | 0.05113 | 0.04615 | 7.04 | 6.05 | 2721.62 | 1514.70 | 4236.32 |
| Total | 891289 | 376 | 0.05113 | 0.04615 | 7.04 | 6.05 | 43523.39 | 20106.35 | 63629.74 |

| Chilled Beams - On Peak Monthly Natural Gas Consumption Cost Analysis | | | |
|---|---|---|---|
| Month | Consumption (therms) | Price per Therm ($) | Cost ($) |
| Jan | 1665 | 1.16 | 1931.4 |
| Feb | 1666 | 1.16 | 1932.56 |
| Mar | 1305 | 1.16 | 1513.8 |
| Apr | 732 | 1.16 | 849.12 |
| May | 629 | 1.16 | 729.64 |
| June | 182 | 1.16 | 211.12 |
| July | 179 | 1.16 | 207.64 |
| Aug | 189 | 1.16 | 219.24 |
| Sep | 599 | 1.16 | 694.84 |
| Oct | 778 | 1.16 | 902.48 |
| Nov | 948 | 1.16 | 1099.68 |
| Dev | 1531 | 1.16 | 1775.96 |
| Total | 10403 | 1.16 | 12067.48 |

| Chilled Beams - On Peak Steam Energy Consumption Cost Analysis | | | |
|---|---|---|---|
| Month | Therms | $ per therm | Cost ($) |
| Jan | 1467 | 1.057 | 1550.62 |
| Feb | 1142 | 1.057 | 1207.09 |
| Mar | 421 | 1.057 | 445.00 |
| Apr | 0 | 1.057 | 0.00 |
| May | 0 | 1.057 | 0.00 |
| June | 0 | 1.057 | 0.00 |
| July | 0 | 1.057 | 0.00 |
| Aug | 0 | 1.057 | 0.00 |
| Sep | 0 | 1.057 | 0.00 |
| Oct | 0 | 1.057 | 0.00 |
| Nov | 221 | 1.057 | 233.60 |
| Dev | 1608 | 1.057 | 1699.66 |
| Total | 4859 | 1.057 | 5135.96 |

| Chilled Beams - On Peak Steam Energy Consumption Cost Analysis | | | |
|---|---|---|---|
| Month | Therms | $ per therm | Cost ($) |
| Jan | 1467 | 1.057 | 1550.62 |
| Feb | 1142 | 1.057 | 1207.09 |
| Mar | 421 | 1.057 | 445.00 |
| Apr | 0 | 1.057 | 0.00 |
| May | 0 | 1.057 | 0.00 |
| June | 0 | 1.057 | 0.00 |
| July | 0 | 1.057 | 0.00 |
| Aug | 0 | 1.057 | 0.00 |
| Sep | 0 | 1.057 | 0.00 |
| Oct | 0 | 1.057 | 0.00 |
| Nov | 221 | 1.057 | 233.60 |
| Dev | 1608 | 1.057 | 1699.66 |
| Total | 4859 | 1.057 | 5135.96 |

| Total Emission Factors for Delivered Natural Gas | | | | |
|---|---|---|---|---|
| Pollutant | lb per CF | Therms | Cubic Feet | Amount of Pollutant (lb) |
| $CO_2$ | 1.16E+00 | 10403 | 938350 | 1088486.00 |
| $NO_x$ | 1.64E-02 | 10403 | 938350 | 15388.94 |
| $SO_x$ | 1.22E+00 | 10403 | 938350 | 1144787.00 |
| $CH_4$ | 7.04E-01 | 10403 | 938350 | 660598.40 |
| $N_2O$ | 2.35E-04 | 10403 | 938350 | 220.51 |
| CO | 1.36E-02 | 10403 | 938350 | 12761.56 |
| Lead | 2.41E-07 | 10403 | 938350 | 0.23 |
| Mercury | 5.51E-08 | 10403 | 938350 | 0.05 |
| PM10 | 8.17E-04 | 10403 | 938350 | 766.63 |
| PM- unspecified | 1.42E-03 | 10403 | 938350 | 1332.46 |
| Solid waste | 1.60E+00 | 10403 | 938350 | 1501360.00 |

| Total Emission Factors for Delivered Electricity | | | |
|---|---|---|---|
| Pollutant | lb per kWh | Consumption | Amounts of pollutant (lb) |
| $CO_2$ | 1.74E+00 | 891289 | 1550842.86 |
| $NO_x$ | 3.00E-03 | 891289 | 2673.87 |
| $SO_x$ | 8.57E-03 | 891289 | 7638.35 |
| $CH_4$ | 3.59E-03 | 891289 | 3199.73 |
| $N_2O$ | 3.87E-05 | 891289 | 34.49 |
| CO | 8.45E-04 | 891289 | 753.14 |
| Lead | 1.39E-07 | 891289 | 0.12 |
| Mercury | 3.36E-08 | 891289 | 0.03 |
| PM10 | 9.26E-05 | 891289 | 82.53 |
| Solid waste | 2.05E-01 | 891289 | 182714.25 |

# Appendix B – Equipment Takeoffs

| VAV Box Takeoffs | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| VAV Tag | # on 1st Floor E | # on 1st Floor W | # on 2nd Floor E | # on 2nd Floor W | # on 3rd Floor E | # on 3rd Floor W | Total | Cost/box | Total Cost |
| A | 5 | 5 | 6 | 0 | 0 | 1 | 17 | 1071 | $18,207.00 |
| B | 1 | 5 | 8 | 0 | 1 | 0 | 15 | 1153 | $17,295.00 |
| C | 7 | 4 | 10 | 0 | 2 | 0 | 23 | 1153 | $26,519.00 |
| D | 2 | 0 | 2 | 0 | 2 | 0 | 6 | 1230 | $8,370.00 |
| E | 4 | 1 | 5 | 0 | 0 | 0 | 10 | 1395 | $13,950.00 |
| F | 4 | 0 | 2 | 0 | 3 | 1 | 10 | 1395 | $14,300.00 |
| G | 3 | 0 | 0 | 0 | 5 | 0 | 8 | 1430 | $11,440.00 |
| | | | | | | | | Total | $110,081.00 |

| Existing Air Handler Quantity Takeoff | | | |
|---|---|---|---|
| Unit Tag | CFM | Cost/unit | Total Cost |
| ERU - 1 | 24000 | 193000 | $193,000.00 |
| ERU - 3 | 24000 | 193000 | $193,000.00 |
| ERU - 5 | 16000 | 129000 | $129,000.00 |
| | | Total Cost | $515,000.00 |

| Existing Supply Diffuser Quantity Takeoff | | | |
|---|---|---|---|
| Unit Tag | # of items | Cost/unit | Total Cost |
| 14" Supply | 15 | 97.01 | 1455.15 |
| 12" Supply | 63 | 93.09 | 5864.67 |
| 10" Supply | 14 | 91.36 | 1279.04 |
| 8" Supply | 44 | 90.82 | 3996.08 |
| 6" Supply | 51 | 89.36 | 4557.36 |
| | | Total | 17152.30 |

| Exisitng Sheet Metal Ductwork Takeoff (First Floor East) | | | | | |
|---|---|---|---|---|---|
| Large Dim | Small Dim | Length (lnft) | Gage Number | Pounds/SF | Pounds of SM |
| 10 | 4 | 85 | 24 | 0.975 | 193 |
| 12" | 3.14 | 85 | 24 | 0.975 | 260 |
| 12 | 5 | 168 | 24 | 0.975 | 464 |
| 12 | 6 | 37 | 24 | 0.975 | 108 |
| 14 | 5 | 242 | 24 | 0.975 | 747 |
| 14 | 7 | 336 | 24 | 0.975 | 1147 |
| 14 | 10 | 38 | 24 | 0.975 | 148 |
| 16 | 8 | 174 | 24 | 0.975 | 679 |
| 16 | 10 | 163 | 24 | 0.975 | 689 |
| 20" | 3.14 | 70 | 22 | 1.220 | 536 |
| 24" | 3.14 | 32 | 20 | 1.465 | 294 |
| 24 | 12 | 198 | 22 | 1.220 | 1449 |
| 44 | 16 | 152 | 22 | 1.220 | 1854 |
| | | | | Total | 8570 |

| Exisitng Sheet Metal Ductwork Takeoff (First Floor West) | | | | | |
|---|---|---|---|---|---|
| Large Dim | Small Dim | Length (lnft) | Gage Number | Pounds/SF | Pounds of SM |
| 10 | 4 | 82 | 24 | 0.975 | 187 |
| 12 | 5 | 25 | 24 | 0.975 | 69 |
| 12 | 6 | 116 | 24 | 0.975 | 339 |
| 12 | 8 | 51 | 24 | 0.975 | 166 |
| 14 | 8 | 40 | 24 | 0.975 | 143 |
| 20 | 10 | 22 | 22 | 1.22 | 134 |
| 10 | 3.14 | 19 | 24 | 0.975 | 48 |
| 20 | 3.14 | 44 | 22 | 1.22 | 281 |
| 22 | 3.14 | 17 | 22 | 1.22 | 119 |
| 24 | 3.14 | 25 | 22 | 1.22 | 192 |
| | | | | Total | 1679 |

| Exisitng Sheet Metal Ductwork Takeoff (Third Floor East) | | | | | |
|---|---|---|---|---|---|
| Large Dim | Small Dim | Length (lnft) | Gage Number | Pounds/SF | Pounds of SM |
| 10 | 4 | 8 | 24 | 0.975 | 18 |
| 10 | 6 | 4 | 24 | 0.975 | 10 |
| 12 | 6 | 81 | 24 | 0.975 | 237 |
| 12 | 8 | 73 | 24 | 0.975 | 237 |
| 12 | 12 | 26 | 24 | 0.975 | 101 |
| 14 | 6 | 61 | 24 | 0.975 | 198 |
| 14 | 7 | 134 | 24 | 0.975 | 457 |
| 14 | 8 | 107 | 24 | 0.975 | 383 |
| 16 | 8 | 63 | 24 | 0.975 | 246 |
| 16 | 10 | 43 | 24 | 0.975 | 182 |
| 18 | 12 | 14 | 24 | 0.975 | 68 |
| 20 | 10 | 13 | 22 | 1.22 | 79 |
| 24 | 10 | 25 | 22 | 1.22 | 173 |
| 24 | 12 | 48 | 22 | 1.22 | 351 |
| 30 | 16 | 161 | 22 | 1.22 | 1506 |
| 30 | 24 | 17 | 22 | 1.22 | 187 |
| 30 | 30 | 10 | 22 | 1.22 | 122 |
| 36 | 20 | 15 | 22 | 1.22 | 171 |
| 46 | 20 | 61 | 22 | 1.22 | 819 |
| 16 | 3.14 | 114 | 22 | 1.22 | 583 |
| 18 | 3.14 | 12 | 22 | 1.22 | 69 |
| 20 | 3.14 | 24 | 22 | 1.22 | 153 |
| 22 | 3.14 | 20 | 22 | 1.22 | 141 |
| 24 | 3.14 | 10 | 22 | 1.22 | 77 |
| 26 | 3.14 | 72 | 22 | 1.22 | 598 |
| 28 | 3.14 | 29 | 20 | 1.465 | 311 |
| 30 | 3.14 | 131 | 20 | 1.465 | 1507 |
| 34 | 3.14 | 46 | 20 | 1.465 | 600 |
| | | | | Total | 9584 |

| Exisitng Sheet Metal Ductwork Takeoff (Third Floor West) | | | | | |
|---|---|---|---|---|---|
| Large Dim | Small Dim | Length (lnft) | Gage Number | Pounds/SF | Pounds of SM |
| 10 | 4 | 17 | 24 | 0.975 | 39 |
| 10 | 6 | 10 | 24 | 0.975 | 26 |
| 12 | 6 | 52 | 24 | 0.975 | 152 |
| 12 | 7 | 26 | 24 | 0.975 | 80 |
| 14 | 10 | 12 | 24 | 0.975 | 47 |
| 14 | 10 | 36 | 24 | 0.975 | 140 |
| 14 | 10 | 22 | 24 | 0.975 | 86 |
| 16 | 8 | 14 | 24 | 0.975 | 55 |
| 16 | 10 | 16 | 24 | 0.975 | 68 |
| 18 | 12 | 28 | 24 | 0.975 | 137 |
| 20 | 12 | 18 | 22 | 1.22 | 117 |
| 24 | 12 | 13 | 22 | 1.22 | 95 |
| 24 | 10 | 19 | 22 | 1.22 | 131 |
| 7 | 3.14 | 52 | 24 | 0.975 | 93 |
| 12 | 3.14 | 42 | 24 | 0.975 | 129 |
| 14 | 3.14 | 24 | 24 | 0.975 | 86 |
| 16 | 3.14 | 10 | 22 | 1.22 | 51 |
| 24 | 3.14 | 53 | 22 | 1.22 | 406 |
| | | | | Total | 1937 |

| Chilled Beam Quanity Takeoffs | | | | | | |
|---|---|---|---|---|---|---|
| Beam Length | # on 1st Floor | # on 2nd Floor | # on 3rd Floor | Total | Cost/beam | Total Cost |
| 4 ft | 13 | 9 | 0 | 22 | $1,052.00 | $23,144.00 |
| 6 ft | 35 | 41 | 38 | 114 | $1,534.00 | $174,876.00 |
| 8 ft | 13 | 29 | 37 | 79 | $2,092.00 | $165,268.00 |
| 10 ft | 2 | 0 | 4 | 6 | $2,565.00 | $15,390.00 |
| | | | | | Total | $378,678.00 |

| Redesign Air Handler Quantity Takeoff | | | |
|---|---|---|---|
| Unit Tag | CFM | Cost/unit | Total Cost |
| ERU - CB | 24000 | $193,000.00 | $193,000.00 |

| Additional Hot and Chilled Water Piping Takeoff | | | |
|---|---|---|---|
| Tag | Length | Cost/lf | Total cost |
| 4" Steel CW | 250 | $70.91 | $17,727.50 |
| 1" Steel CW | 650 | $22.06 | $14,339.00 |
| 2" Copper CW | 1000 | $39.79 | $39,790.00 |
| 1.5" Copper CW | 640 | $30.19 | $19,321.60 |
| 1.25" Copper CW | 400 | $25.05 | $10,020.00 |
| 1" Copper CW | 1650 | $19.80 | $32,670.00 |
| .75" Copper CW | 650 | $16.61 | $10,796.50 |
| | | Total | $144,664.60 |

# Appendix C – Room Assignments

| Room # | Space Name | $A_z$ | Sensible Load (Mbh) | CFM Supply | Aux CFM | Ratio | Chilled Beam | # of Beams | Length | I.R./cfm | Primary CFM | Cooling Capacity | Linear Feet |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 104 | Entry Lobby | 1717 | 8.9 | 130 | 858 | 6.6 | DID-302-US | 4 | 6 | A-11 | 264 | 10.4 | 26 |
| 113 | Office | 107 | 1 | 50 | 174 | 3.5 | DID-302-US | 1 | 4 | C-13 | 52 | 1.4 | 4 |
| 114 | Office | 113 | 1 | 50 | 174 | 3.5 | DID-302-US | 1 | 4 | C-13 | 52 | 1.4 | 4 |
| 116 | Building Manager | 109 | 1 | 50 | 174 | 3.5 | DID-302-US | 1 | 4 | C-13 | 52 | 1.4 | 4 |
| 117 | Work/Storage | 157 | 1 | 50 | 159 | 3.2 | DID-302-US | 1 | 4 | C-13 | 52 | 1.4 | 4 |
| 118 | Conference | 227 | 5.3 | 250 | 837 | 3.3 | DID-302-US | 2 | 6 | C-25 | 300 | 6.1 | 12 |
| 119 | Directory | 112 | 2.3 | 65 | 354 | 5.4 | DID-302-US | 1 | 6 | A-11 | 66 | 2.6 | 6 |
| 120 | VP assistant | 112 | 2.3 | 65 | 354 | 5.4 | DID-302-US | 1 | 6 | A-11 | 66 | 2.6 | 6 |
| 121 | Univ UN Oper | 938 | 7.8 | 220 | 1134 | 5.2 | DID-302-US | 5 | 4 | A-11 | 220 | 8.6 | 20 |
| 124 | Coop Act | 309 | 1.2 | 50 | 189 | 3.8 | DID-302-US | 1 | 6 | C-13 | 78 | 2.1 | 6 |
| 125 | Dir Coop | 93 | 1.2 | 65 | 174 | 2.7 | DID-302-US | 1 | 6 | C-13 | 78 | 2.1 | 6 |
| 126 | Stor/Server | 81 | 0.3 | 65 | 174 | 2.7 | DID-302-US | 1 | 6 | C-13 | 78 | 2.1 | 6 |
| 136 | Café | 1255 | 16.2 | 820 | 1640 | 2.0 | DID-302-US | 6 | 8 | C-25 | 912 | 18.4 | 48 |
| 137 | Café Storage | 302 | 1.2 | 50 | 174 | 3.5 | DID-302-US | 1 | 4 | C-13 | 52 | 1.4 | 4 |
| 139 | Bank | 782 | 3.3 | 130 | 513 | 3.9 | DID-302-US | 1 | 10 | C-13 | 130 | 4.1 | 10 |
| 140 | Bookstore Storage | 4828 | 24.2 | 600 | 3428 | 5.7 | DID-302-US | 7 | 8 | A-11 | 616 | 24.2 | 56 |
| 142 | Accounts | 115 | 0.5 | 33 | 165 | 5.0 | DID-302-US | 1 | 4 | C-13 | 52 | 1.4 | 4 |
| 143 | Accounts Receivable | 110 | 0.4 | 40 | 168 | 4.2 | DID-302-US | 1 | 4 | C-13 | 52 | 1.4 | 4 |
| 144 | Store manager | 103 | 0.5 | 33 | 165 | 5.0 | DID-302-US | 1 | 4 | C-13 | 52 | 1.4 | 4 |
| 146 | Employee Lounge | 211 | 1.2 | 114 | 251 | 2.2 | DID-302-US | 1 | 6 | C-19 | 114 | 2.5 | 6 |
| 147 | Bookstore Textbooks | 400 | 1.5 | 120 | 450 | 3.8 | DID-302-US | 1 | 10 | C-13 | 130 | 2.6 | 10 |
| 148 | Vestibule | 76 | 1.4 | 82 | 200 | 2.4 | DID-302-US | 1 | 6 | C-13 | 78 | 2.1 | 6 |
| 149 | Dressing room | 38 | 0.6 | 75 | 193 | 2.6 | DID-302-US | 1 | 6 | C-13 | 78 | 2.1 | 6 |
| 150 | Bookstore | 7277 | 76.8 | 1250 | 10665 | 8.5 | DID-602-US | 21 | 6 | C-10 | 1260 | 79.8 | 126 |
| 202 | Small Lounge | 2487 | 10.9 | 800 | 1650 | 2.1 | DID-302-US | 4 | 8 | C-25 | 800 | 16.2 | 32 |
| 203 | Cultural Lounge | 836 | 7.6 | 330 | 1173 | 3.6 | DID-302-US | 3 | 6 | B-18 | 330 | 10.4 | 18 |
| 204 | Fireplace Lounge | 1349 | 26.3 | 1100 | 3981 | 3.6 | DID-302-US | 6 | 8 | C-25 | 1200 | 34.1 | 48 |
| 236 | Student Lounge | 479 | 6.7 | 165 | 980 | 5.9 | DID-302-US | 3 | 6 | A-11 | 198 | 7.8 | 18 |
| 236 | Work Area | 2786 | 24.5 | 1650 | 3300 | 2.0 | DID-302-US | 11 | 6 | C-25 | 1650 | 33.3 | 66 |
| 237 | Student Orgs | 250 | 5 | 85 | 713 | 8.4 | DID-302-US | 2 | 6 | A-11 | 132 | 5.2 | 12 |
| 238 | Student Orgs | 250 | 7.5 | 170 | 1079 | 6.3 | DID-302-US | 3 | 6 | A-11 | 198 | 7.8 | 18 |
| 239 | Student Orgs | 250 | 7.5 | 170 | 1079 | 6.3 | DID-302-US | 3 | 6 | A-11 | 198 | 7.8 | 18 |
| 240 | Office | 83 | 1 | 50 | 174 | 3.5 | DID-302-US | 1 | 4 | C-13 | 52 | 1.4 | 4 |
| 241 | Office | 83 | 1 | 50 | 174 | 3.5 | DID-302-US | 1 | 4 | C-13 | 52 | 1.4 | 4 |
| 242 | Office | 84 | 1 | 50 | 174 | 3.5 | DID-302-US | 1 | 4 | C-13 | 52 | 1.4 | 4 |
| 243 | Student Orgs | 240 | 11 | 255 | 1558 | 6.1 | DID-302-US | 4 | 8 | A-11 | 352 | 13.8 | 32 |
| 244 | Student Orgs | 240 | 11 | 255 | 1558 | 6.1 | DID-302-US | 4 | 8 | A-11 | 352 | 13.8 | 32 |
| 245 | Student Orgs | 240 | 11 | 255 | 1558 | 6.1 | DID-302-US | 4 | 8 | A-11 | 352 | 13.8 | 32 |
| 247 | Conference | 201 | 5.6 | 175 | 389 | 2.2 | DID-302-US | 1 | 8 | C-25 | 200 | 7.7 | 8 |
| 248 | Office | 172 | 1.4 | 50 | 181 | 3.6 | DID-302-US | 1 | 4 | C-13 | 52 | 1.4 | 4 |
| 248 | Office | 55 | 0.4 | 50 | 155 | 3.1 | DID-302-US | 1 | 4 | C-13 | 52 | 1.4 | 4 |
| 253 | Safe Room | 91 | 0.1 | 25 | 162 | 6.5 | DID-302-US | 1 | 4 | C-13 | 52 | 1.4 | 4 |
| 254 | Office | 87 | 1.1 | 50 | 177 | 3.5 | DID-302-US | 1 | 4 | C-13 | 52 | 1.4 | 4 |
| 255 | Office | 87 | 1.1 | 50 | 177 | 3.5 | DID-302-US | 1 | 4 | C-13 | 52 | 1.4 | 4 |
| 256 | Womens Center | 413 | 7.2 | 150 | 740 | 4.9 | DID-302-US | 5 | 6 | A-5 | 150 | 7.4 | 30 |
| 257 | Office | 93 | 1.2 | 75 | 375 | 5.0 | DID-302-US | 1 | 6 | C-13 | 78 | 2.1 | 6 |
| 258 | Office | 93 | 1.2 | 75 | 375 | 5.0 | DID-302-US | 1 | 6 | C-13 | 78 | 2.1 | 6 |
| 259 | Office | 93 | 1.2 | 75 | 375 | 5.0 | DID-302-US | 1 | 6 | C-13 | 78 | 2.1 | 6 |
| 260 | Resource Area | 233 | 5.4 | 100 | 553 | 5.5 | DID-302-US | 3 | 8 | A-5 | 120 | 5.9 | 24 |
| 261 | Student Orgs | 232 | 5.4 | 100 | 550 | 5.5 | DID-302-US | 3 | 8 | A-5 | 120 | 5.9 | 24 |
| 262 | Office | 92 | 1.2 | 75 | 375 | 5.0 | DID-302-US | 1 | 6 | C-13 | 78 | 2.1 | 6 |
| 263 | Office | 92 | 1.2 | 75 | 375 | 5.0 | DID-302-US | 1 | 6 | C-13 | 78 | 2.1 | 6 |
| 264 | Office | 92 | 1.2 | 75 | 375 | 5.0 | DID-302-US | 1 | 6 | C-13 | 78 | 2.1 | 6 |
| 266 | Paint | 81 | 0.3 | 25 | 162 | 6.5 | DID-302-US | 1 | 4 | C-13 | 52 | 1.4 | 4 |
| 301 | Circulation/Lobby | 3360 | 50.4 | 1650 | 3300 | 2.0 | DID-302-US | 11 | 6 | C-25 | 1650 | 64.8 | 66 |
| 303 | Theater/Multipurpose | 2803 | 72.4 | 2000 | 10402 | 5.2 | DID-302-US | 23 | 8 | A-11 | 2021 | 79.5 | 184 |
| 312 | Catering Kitchen | 1042 | 20.6 | 400 | 2911 | 7.3 | DID-302-US | 10 | 8 | A-5 | 400 | 21.4 | 80 |
| 328 | Circulation | 1440 | 4.3 | 425 | 902 | 2.1 | DID-302-US | 3 | 6 | C-25 | 450 | 9.1 | 18 |
| 330 | Large Meeting | 954 | 5.9 | 825 | 1669 | 2.0 | DID-302-US | 6 | 6 | C-25 | 900 | 18.1 | 36 |
| 331 | Large Meeting | 954 | 4.9 | 825 | 1659 | 2.0 | DID-302-US | 6 | 6 | C-25 | 900 | 18.1 | 36 |
| 333 | Small Meeting | 486 | 5.1 | 350 | 888 | 2.5 | DID-302-US | 2 | 8 | C-25 | 400 | 8.1 | 16 |
| 334 | Small Meeting | 435 | 5 | 425 | 850 | 2.0 | DID-302-US | 2 | 8 | C-25 | 400 | 8.1 | 16 |
| 337 | Medium Meeting | 720 | 12.8 | 825 | 1650 | 2.0 | DID-302-US | 6 | 6 | C-25 | 900 | 18.1 | 36 |
| 339 | Large Meeting | 1237 | 10.5 | 1000 | 2143 | 2.1 | DID-302-US | 4 | 10 | C-25 | 1000 | 20.1 | 40 |
| 340 | Medium Meeting | 698 | 11.4 | 825 | 1650 | 2.0 | DID-302-US | 6 | 6 | C-25 | 900 | 18.1 | 36 |
| 202B | Upper Lobby | 1591 | 14.3 | 750 | 1500 | 2.0 | DID-302-US | 5 | 6 | C-25 | 750 | 15.2 | 30 |
| | | | | 21367 | 76938 | | | 221 | | | 22843 | 698.23 | 1466 |

| Room # | Space Name | $A_z$ | $R_a$ | $R_p$ | $P_z$ | Vbz=Voz | CFM | $Q_L$ | Latent CFM |
|---|---|---|---|---|---|---|---|---|---|
| 102 | Corridor | 2518 | 0.06 | 0 | 0 | 151.08 | 1000 | 0 | 0 |
| 104 | Entry Lobby | 1717 | 0.06 | 5 | 5 | 128.02 | 1450 | 1000 | 82 |
| 105 | Storage | 81 | 0.12 | 0 | 0 | 9.72 | 100 | 0 | 0 |
| 106 | Corridor | 713 | 0.06 | 0 | 0 | 42.78 | 400 | 0 | 0 |
| 108 | Utility | 35 | 0.12 | 0 | 0 | 4.2 | 50 | 0 | 0 |
| 109 | Womens Toilet | 211 | 0.06 | 0 | 0 | 0 | 60 | 0 | 0 |
| 110 | Mens Toilet | 211 | 0.06 | 0 | 0 | 0 | 60 | 0 | 0 |
| 113 | Office | 107 | 0.12 | 10 | 1 | 22.84 | 100 | 200 | 16 |
| 114 | Office | 113 | 0.12 | 10 | 1 | 23.56 | 100 | 200 | 16 |
| 116 | Building Manager | 109 | 0.12 | 10 | 2 | 33.08 | 100 | 400 | 33 |
| 117 | Work/Storage | 157 | 0.12 | 0 | 0 | 18.84 | 200 | 0 | 0 |
| 118 | Conference | 227 | 0.12 | 10 | 15 | 177.24 | 410 | 3000 | 245 |
| 119 | Directory | 112 | 0.12 | 10 | 4 | 53.44 | 190 | 800 | 65 |
| 120 | VP assistant | 112 | 0.12 | 10 | 2 | 33.44 | 240 | 400 | 33 |
| 121 | Univ UN Oper | 938 | 0.12 | 10 | 10 | 212 | 960 | 400 | 163 |
| 122 | Storage | 61 | 0.12 | 0 | 0 | 7.32 | 50 | 0 | 0 |
| 124 | Coop Act | 309 | 0.12 | 10 | 1 | 47.08 | 265 | 200 | 16 |
| 125 | Dir Coop | 93 | 0.12 | 10 | 1 | 21.16 | 90 | 200 | 16 |
| 126 | Stor/Server | 81 | 0.12 | 10 | 1 | 19.72 | 200 | 200 | 16 |
| 133 | Corridor | 1416 | 0.06 | 0 | 0 | 84.96 | 530 | 0 | 0 |
| 135 | Corridor | 361 | 0.12 | 0 | 0 | 43.32 | 225 | 0 | 0 |
| 136 | Café | 1255 | 0.18 | 10 | 50 | 725.9 | 850 | 10000 | 817 |
| 137 | Café Storage | 302 | 0.12 | 0 | 0 | 36.24 | 400 | 0 | 0 |
| 138 | UPS | 1916 | 0.12 | 0 | 0 | 229.92 | 1200 | 0 | 0 |
| 139 | Bank | 782 | 0.06 | 10 | 8 | 126.92 | 620 | 1600 | 131 |
| 140 | Storage | 4828 | 0.12 | 0 | 30 | 579.36 | 5620 | 6000 | 490 |
| 141 | Utility | 40 | 0.12 | 0 | 1 | 4.8 | 50 | 200 | 16 |
| 142 | Accounts | 115 | 0.12 | 5 | 2 | 23.8 | 150 | 400 | 33 |
| 143 | Accounts Receivable | 110 | 0.12 | 5 | 2 | 23.2 | 150 | 400 | 33 |
| 144 | Store manager | 103 | 0.12 | 5 | 2 | 22.36 | 150 | 400 | 33 |
| 145 | IT/Copy | 130 | 0.06 | 0 | 0 | 7.8 | 50 | 0 | 0 |
| 146 | Employee Lounge | 211 | 0.12 | 7.5 | 7 | 77.82 | 250 | 1400 | 114 |
| 147 | Bookstore Textbooks | 400 | 0.12 | 7.5 | 7 | 100.5 | 350 | 1400 | 114 |
| 148 | Vestibule | 76 | 0.06 | 0 | 0 | 4.56 | 50 | 0 | 0 |
| 149 | Dressing room | 38 | 0.06 | 0 | 1 | 2.28 | 110 | 200 | 16 |
| 149 | Storage | 38 | 0.06 | 0 | 0 | 2.28 | 100 | 0 | 0 |
| 150 | Bookstore | 7277 | 0.12 | 5 | 75 | 1248.24 | 11520 | 15000 | 1225 |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 202 | Small Lounge | 2487 | 0.12 | 10 | 50 | 798.44 | 1000 | 10000 | 817 |
| 202 | Storage | 106 | 0.12 | 0 | 0 | 12.72 | 75 | 0 | 0 |
| 203 | Cultural Lounge | 836 | 0.12 | 10 | 20 | 300.32 | 1180 | 4000 | 327 |
| 204 | Fireplace Lounge | 1349 | 0.12 | 10 | 65 | 811.88 | 2600 | 13000 | 1062 |
| 218 | Corridor | 741 | 0.06 | 0 | 0 | 44.46 | 800 | 0 | 0 |
| 228 | Mens Toilet | 258 | 0.06 | 0 | 0 | 15.48 | 250 | 0 | 0 |
| 229 | Womens Toilet | 355 | 0.06 | 0 | 0 | 21.3 | 250 | 0 | 0 |
| 231 | Utility | 31 | 0.12 | 0 | 0 | 3.72 | 100 | 0 | 0 |
| 233 | Corridor | 212 | 0.06 | 0 | 0 | 12.72 | 800 | 0 | 0 |
| 233 | Corridor | 643 | 0.06 | 0 | 0 | 38.58 | 300 | 0 | 0 |
| 235 | Commuter Pantry | 93 | 0.12 | 0 | 0 | 11.16 | 125 | 0 | 0 |
| 236 | Student Lounge | 479 | 0.12 | 10 | 10 | 157.48 | 1200 | 2000 | 163 |
| 236 | Work Area | 2786 | 0.12 | 10 | 100 | 1334.32 | 1910 | 20000 | 1634 |
| 237 | Student Orgs | 250 | 0.12 | 10 | 5 | 80 | 425 | 1000 | 82 |
| 238 | Student Orgs | 250 | 0.12 | 10 | 5 | 80 | 400 | 1000 | 82 |
| 239 | Student Orgs | 250 | 0.12 | 10 | 5 | 80 | 300 | 1000 | 82 |
| 240 | Office | 83 | 0.12 | 10 | 1 | 19.96 | 75 | 200 | 16 |
| 241 | Office | 83 | 0.12 | 10 | 1 | 19.96 | 75 | 200 | 16 |
| 242 | Office | 84 | 0.12 | 10 | 1 | 20.08 | 140 | 200 | 16 |
| 243 | Student Orgs | 240 | 0.12 | 10 | 5 | 78.8 | 400 | 1000 | 82 |
| 244 | Student Orgs | 240 | 0.12 | 10 | 5 | 78.8 | 400 | 1000 | 82 |
| 245 | Student Orgs | 240 | 0.12 | 10 | 5 | 78.8 | 400 | 1000 | 82 |
| 247 | Conference | 201 | 0.12 | 10 | 10 | 124.12 | 500 | 2000 | 163 |
| 248 | Office | 172 | 0.12 | 10 | 1 | 30.64 | 550 | 200 | 16 |
| 248 | Office | 55 | 0.12 | 10 | 1 | 16.6 | 250 | 200 | 16 |
| 253 | Safe Room | 91 | 0.12 | 0 | 0 | 10.92 | 75 | 0 | 0 |
| 254 | Office | 87 | 0.12 | 10 | 1 | 20.44 | 75 | 200 | 16 |
| 255 | Office | 87 | 0.12 | 10 | 1 | 20.44 | 75 | 200 | 16 |
| 256 | Womens Center | 413 | 0.12 | 10 | 5 | 99.56 | 500 | 1000 | 82 |
| 257 | Office | 93 | 0.12 | 10 | 1 | 21.16 | 310 | 200 | 16 |
| 258 | Office | 93 | 0.12 | 10 | 1 | 21.16 | 310 | 200 | 16 |
| 259 | Office | 93 | 0.12 | 10 | 1 | 21.16 | 310 | 200 | 16 |
| 260 | Resource Area | 233 | 0.12 | 10 | 4 | 67.96 | 690 | 800 | 65 |
| 261 | Student Orgs | 232 | 0.12 | 10 | 5 | 77.84 | 850 | 1000 | 82 |
| 262 | Office | 92 | 0.12 | 10 | 1 | 21.04 | 310 | 200 | 16 |
| 263 | Office | 92 | 0.12 | 10 | 1 | 21.04 | 310 | 200 | 16 |
| 264 | Office | 92 | 0.12 | 10 | 1 | 21.04 | 310 | 200 | 16 |
| 266 | Paint | 81 | 0.12 | 0 | 0 | 9.72 | 300 | 0 | 0 |
| 301 | Circulation/Lobby | 3360 | 0.06 | 5 | 100 | 701.6 | 3600 | 20000 | 1634 |
| 303 | Theater/Multipurpose | 2803 | 0.06 | 10 | 120 | 1368.18 | 7000 | 24000 | 1961 |
| 312 | Catering Kitchen | 1042 | 0.18 | 10 | 20 | 387.56 | 1750 | 4000 | 327 |
| 313 | Catering Storage | 380 | 0.12 | 0 | 0 | 45.6 | 200 | 0 | 0 |
| 314 | Green Room | 142 | 0.06 | 0 | 0 | 8.52 | 250 | 0 | 0 |
| 314 | Toilet | 125 | 0.06 | 0 | 0 | 7.5 | 20 | 0 | 0 |
| 319 | Mens Toilet | 340 | 0.06 | 0 | 0 | 20.4 | 250 | 0 | 0 |
| 320 | Womens Toilet | 454 | 0.06 | 0 | 0 | 27.24 | 250 | 0 | 0 |
| 321 | Custodial | 25 | 0.12 | 0 | 0 | 3 | 100 | 0 | 0 |
| 323 | Toilet | 55 | 0.06 | 0 | 0 | 3.3 | 100 | 0 | 0 |
| 324 | Corridor | 525 | 0.06 | 0 | 0 | 31.5 | 165 | 0 | 0 |
| 325 | Storage | 275 | 0.12 | 0 | 0 | 33 | 165 | 0 | 0 |
| 326 | Tech | 119 | 0.12 | 10 | 2 | 34.28 | 100 | 400 | 33 |
| 327 | Pantry | 127 | 0.12 | 0 | 0 | 15.24 | 140 | 0 | 0 |
| 328 | Circulation | 1440 | 0.06 | 5 | 25 | 211.4 | 1200 | 5000 | 408 |
| 330 | Large Meeting | 954 | 0.12 | 10 | 50 | 614.48 | 2400 | 10000 | 817 |
| 331 | Large Meeting | 954 | 0.12 | 10 | 50 | 614.48 | 2100 | 10000 | 817 |
| 333 | Small Meeting | 486 | 0.12 | 10 | 20 | 258.32 | 900 | 4000 | 327 |
| 334 | Small Meeting | 435 | 0.12 | 10 | 25 | 302.2 | 900 | 5000 | 408 |
| 337 | Medium Meeting | 720 | 0.12 | 10 | 50 | 586.4 | 1700 | 10000 | 817 |
| 339 | Large Meeting | 1237 | 0.12 | 10 | 60 | 748.44 | 2100 | 12000 | 980 |
| 340 | Medium Meeting | 698 | 0.12 | 10 | 50 | 583.76 | 1400 | 10000 | 817 |
| 341 | Storage | 435 | 0.12 | 0 | 0 | 52.2 | 325 | 0 | 0 |
| 202B | Upper Lobby | 1591 | 0.12 | 10 | 45 | 640.92 | 800 | 9000 | 735 |

# Appendix D – Air Handler Design

**Fan section** — **Module Position:** 1

| Fan sec [1]-1 | | | |
|---|---|---|---|
| Run Result | Meets | Fan airflow | 24731 cfm |
| Section type | Fan | Overall ESP | 1.000 in H2O |
| Fan application | Exhaust fan | Unit entering ESP | 0.500 in H2O |
| Unit size | 50 | Unit discharge ESP | 0.500 in H2O |
| Inlet location | Front inlet | Elevation | 0.00 ft |
| Fan orientation | Plenum fan | Minimum temperature | 40.00 F |
| Fan discharge | Back top | Design temperature | 70.00 F |
| Access door location | Right | Fan size and type | 40in. belt-drive plenum, class 1 |
| Drive location | Right side drive | Plenum fan back discharge | 1st back rectangular opening |
| Design sequence | D | Total brake horsepower | 24.409 hp |
| Motor horsepower per fan | 25 hp | Total brake horsepower at min temp | 25.875 hp |
| Motor class | NEMA premium compliant ODP | Total static pressure | 3.192 in H2O |
| Motor voltage | 460/3 | Speed | 949 rpm |
| Cycle | 60 cycles/sec | Fan module pressure drop | 1.257 in H2O |
| Drive service factor | 1.5 fixed drive | Static pressure origin | Program calculated |
| Motor RPM | 1800 | | |

**Wheel** — **Module Position:** 6

| | | | |
|---|---|---|---|
| Wheel type | Energy wheel | EW Outside air bypass damper | No |
| Wheel size | 25000 CFM | Recirculation damper | No |
| Motor voltage | 460/3 | Filter type | 4" high eff. - 95% eff - MERV 14 |
| Leaving supply airflow | 24678 cfm | Section length | 64.750 in |
| Supply air wheel PD | 1.146 in H2O | Section height | 151.750 in |
| CDQ Regeneration air bypass damper | No | Section width | 125.500 in |
| CDQ Supply air bypass damper | No | Section weight | 2470.0 lb |
| EW Exhaust air bypass damper | Yes | | |

**Fan section** — **Module Position:** 8

| Fan sec [8]-1 | | | |
|---|---|---|---|
| Run Result | Meets | Overall ESP | 2.000 in H2O |
| Section type | Fan | Unit entering ESP | 1.000 in H2O |
| Fan application | Supply fan | Unit discharge ESP | 1.000 in H2O |
| Unit size | 50 | Elevation | 0.00 ft |
| Inlet location | Back inlet | Minimum temperature | 40.00 F |
| Fan orientation | Plenum fan | Design temperature | 70.00 F |
| Fan discharge | Front top | Fan size and type | 40in. belt-drive plenum, class 2 |
| Access door location | Right | Total brake horsepower | 38.478 hp |
| Drive location | Right side drive | Total brake horsepower at min temp | 40.789 hp |
| Design sequence | D | Total static pressure | 5.560 in H2O |
| Motor horsepower per fan | 40 hp | Speed | 1116 rpm |
| Motor class | NEMA premium compliant ODP | Fan module pressure drop | 2.028 in H2O |
| Motor voltage | 460/3 | Section height | 75.750 in |
| Cycle | 60 cycles/sec | Section length | 57.500 in |
| Drive service factor | 1.5 fixed drive | Section width | 125.500 in |
| Motor RPM | 1800 | Section weight | 2401.0 lb |
| Fan airflow | 24678 cfm | Static pressure origin | Program calculated |

**Filter section** — **Module Position:** 10

| | | | |
|---|---|---|---|
| Section type | Filter | Filter area | 50.00 sq ft |
| Unit size | 50 | Filter face velocity | 494 ft/min |
| Filter type | Long Bag filter | Filter pressure drop | 0.831 in H2O |
| Filter frame | Bag/cartridge filter frame | Prefilter pressure drop | 0.650 in H2O |
| Access door location | Right | Filter section pressure drop | 1.481 in H2O |
| Primary filter type 1 | 30in. bag - 85% eff - MERV 13 | Section length | 37.250 in |
| Prefilter filter type | 2" Coated pleated media - MERV 7 | Section width | 125.500 in |
| Design sequence | B | Section height | 75.750 in |
| Filter airflow | 24678 cfm | Section weight | 710.5 lb |
| Filter condition | Mid-life | | |

**Coil section** — **Module Position:** 11

**Coil s [11]-1**

| | | | |
|---|---|---|---|
| Run Result | Exceeds | Coil type | NS |
| Section type | Horizontal coil | Rows | 1 row |
| Unit size | 50 | Fin type | Sigma flo fins |
| Section size | Medium | Fin material | Aluminum fins |
| Wheel capacity | Use energy wheel values | Tube diameter | 1in. tube diameter (25.4 mm) |
| Coil application | Heating coil | Tube matl/wall thickness | .031" (0.787mm) copper tubes |
| Changeover coil | No | Corrosion resistant coating | None |
| System type | Steam | Coil face velocity | 524 ft/min |
| Coil supply/cabinet side | Right | Air pressure drop | 0.080 in H2O |
| Coil casing | Galvanized | Fluid volume | 7.95 gal |
| Coil height | Unit coil height | Steam pressure drop | 4.593 in H2O |
| Drain pan | Galvanized | Coil condensate | 947.14 lb/hr |
| Drain connection location | Right | Total cap coil #1 | 448.05 MBh |
| Design sequence | B | Total cap coil #2 | 448.05 MBh |
| Apply AHRI ranges | Yes | Coil face area | 47.08 sq ft |
| Coil performance airflow | 24678 cfm | Coil rigging weight | 303.5 lb |
| Coil elevation | 0.00 ft | Coil section pressure drop | 0.080 in H2O |
| Entering dry bulb | 49.92 F | Section length | 14.000 in |
| Leaving dry bulb | 83.41 F | Section height | 75.750 in |
| Total capacity | 896.10 MBh | Section width | 125.500 in |
| Fin spacing | 42 Per Foot | Section weight | 620.5 lb |
| Steam pressure | 15.00 psig | | |

# Appendix E – Girder Redesign Calculations

**Girder Redesign:**

Sizing Girder:

$W_{TL}$ = 1.2D + 1.6L
Superimposed Dead Load – 15 psf
Weight of Prestressed Plank – 86.25 psf

$W_{TL}$ = 1.2( 15 + 86.25 ) + 1.6( 100 ) = 281.5 psf
$M_U$ = ( 281.5 )( 26 )( 24 )$^2$/ 8 = 527 ft*kip
From the Steel Construction Manual – W18X71 @ 548 psf capacity
$M_U$ = [ ( 281.5 )( 26 ) + 71 ] ( 24 )$^2$/ 8 = 532.1 ft-kip < 548 ft-kip therefore W18X71 is OK

Live Load Deflection

$\Delta_{LL}$ = 5 $W_{LL}$ $L^4$ ( 1728) / ( 384 E I )
E = 29,000,000 psi
$I_{W18X71}$= 1170 in$^4$
$\Delta_{LL}$ = 5 (100*4) 24$^4$ ( 1728) / ( 384 * 4286826 * 1170 ) = 0.088 inches

Allowable Live Load Deflection:

$\Delta_{LL}$ = L / 360 = ( 24 ft * 12 in/ft ) / 360 = 0.80 inches
0.088 inches < 0.80 inches therefore OK

Total Load Deflection:

$\Delta_{TL}$ = 5 $W_{TL}$ $L^4$ ( 1728) / ( 384 E I )
E = 29,000,000 psi
$I_{W18X71}$= 1170 in$^4$
$\Delta_{TL}$ = 5 (130*4) 24$^4$ ( 1728) / ( 384 * 4286826 * 1170 ) = 0.11 inches
Allowable Total Load Deflection:
$\Delta_{TL}$ = L / 240 = ( 24 ft * 12 in/ft ) / 240 = 1.2 inches
0.11 inches < 1.2 inches therefore OK

| Beam Sizing and Deflection Checks | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Beam Tag | W | Length of Beam | Weight of Beam | Trib Width | Inertia (I) | Moment ($M_U$) | With S-W ($M_U$) | Capacity | $\Delta_{LL}$ | Allowable $\Delta_{LL}$ | $\Delta_{TL}$ | Allowable $\Delta_{TL}$ | Check |
| | psf | ft | plf | ft | $in^4$ | ft-k | ft-k | ft-k | in | in | in | in | |
| W14X68 | 281.5 | 21 | 68 | 26 | 722 | 403.5 | 407.2 | 431 | 0.08 | 0.7 | 0.11 | 1.05 | ✓ |
| W14X74 | 286 | 21 | 74 | 28.5 | 795 | 449.3 | 453.4 | 473 | 0.08 | 0.7 | 0.10 | 1.05 | ✓ |
| W18X71 | 281.5 | 24 | 71 | 26 | 1170 | 527.0 | 532.1 | 548 | 0.09 | 0.8 | 0.11 | 1.2 | ✓ |
| W18X76 | 286 | 24 | 76 | 28.5 | 1330 | 586.9 | 592.3 | 611 | 0.08 | 0.8 | 0.10 | 1.2 | ✓ |
| W18X97 | 286 | 27 | 97 | 28.5 | 1750 | 742.8 | 751.6 | 791 | 0.09 | 0.9 | 0.12 | 1.35 | ✓ |
| W21X83 | 281.5 | 27 | 83 | 26 | 1830 | 666.9 | 674.5 | 735 | 0.09 | 0.9 | 0.12 | 1.35 | ✓ |