Senior Thesis Final Report:

An In-depth Look at a Green Roof

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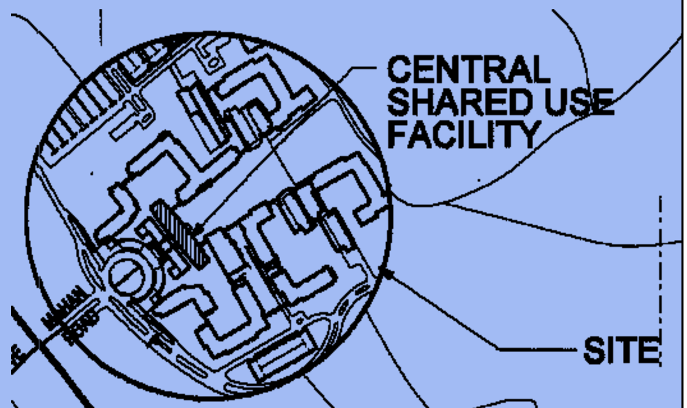
Mechanical
Central Shared Use Facility
Silver Spring, Maryland

Presented to: AE Faculty

Central Shared Use Facility
Silver Spring Maryland

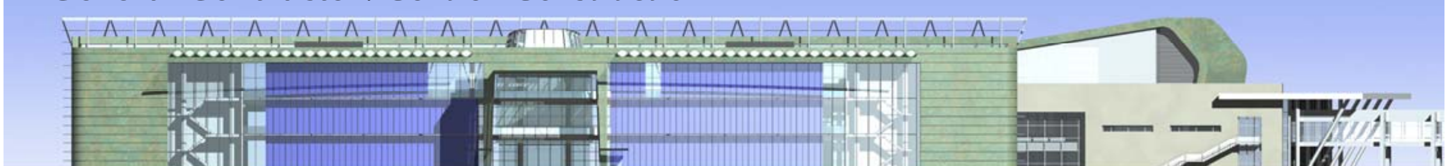
General Information

Size: 11,695 sq. meters
3 stories, 1 basement
Cost: $24,241,000 Lump Sum Contract
Construction Dates: 10/05/04 - 3/29/06
Site: Old Navel Research Center



Project Team

Owner: U.S. General Services Administration
Occupant: Food and Drug Administration
Architect/Design: Kling Lindquist
General Contractor: Centrex Construction



Lighting/Electrical

- The transformers are 480V Delta and 208/120 wye.
- Power is generated by natural gas turbines at a CUP; backup power is supplied by PEPCO.
- The lighting is mainly fluorescent.

Structural

- Post Tensioned Concrete used for slab and column construction
- Spread Footings used to support the structure.

Mechanical

- Central Chiller/Boiler plant provides cold/hot water to the building
- 7 AHU’s supply and distribute conditioned air.
- VAV boxes control airflow throughout building
- Plenum return system

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http://www.arche.psu.edu/thesis/eportfolio/current/portfolios/jsb275

Report Contents

Figures and Tables

The building studied in this report is a 3 story, 126,000 sf office building. At the center of the Food and Drug Administrations campus in Silver Spring Maryland, the building houses a gym, cafeteria, data center, auditoriums, and libraries. The third floor has been left bare during the first design and construction phase, but the space has been reserved for a 26,000 sf library. The purpose of this thesis is to design a VAV system for the future library, and use the system to analyze how the green roof will affect the space, and how much extra costs are associated with the green roof.

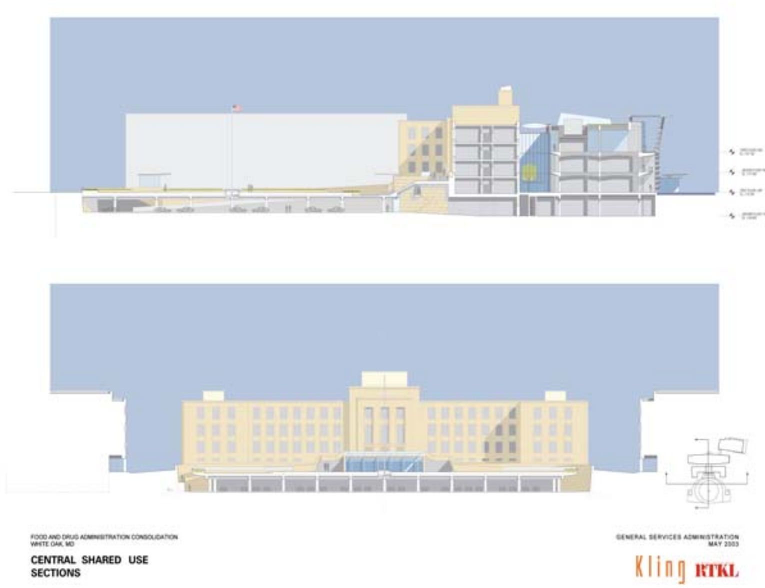
To help design and simulate the VAV system, the existing space conditions were used to model the future library in Trane's TRACE program. After the initial VAV system was designed, the simulated green roof was slowly reduced in size and the system was re-simulated in order to see how the size of the green roof affected the design. At design, the green roof covered 66% of the roof. The off-design conditions analyzed were green roofs that covered 60, 55, 50, 45, 40, 35, and 30% of the total roof area. As the green roof was taken away, a conventional concrete roof was added in its place. Energy savings, rainwater reduction, and first costs were the main categories evaluated for this thesis.

Table 1 - Summary

Green Roof (%)	Total Cooling Load (ton)	Runoff Reduction (%)	Additional Fist Cost ($)	Estimated Annual Energy Savings ($)
66	105.9	48	202,184	25,825
60	109.2	45	183,804	23,477
55	112.0	42	168,487	21,521
50	114.8	39	153,170	19,564
45	117.7	36	137,853	17,608
40	120.5	33	122,536	15,652
35	123.6	30	107,219	13,695
30	126.4	27	91,902	11,739

Based on the results above, it is clear that the designed green roof covering 66% of the total roof is the most valuable design for the owner. The additional first cost to the project is compensated by the energy savings and extended lifetime of the roof. There was no most beneficial size for the green roof, but it was determined that the bigger the green roof, the bigger the energy savings. Therefore, if an owner can pay for the additional first costs of a green roof (about $12/sf) the owner should cover as much of the roof as possible.

Even though the maintenance costs and energy savings cannot be predicted very accurately, it is important in today's society to conserve as much energy as possible. By building a green roof on the CSUF, the government is insuring that the energy consumption will be lower, no matter how much extra money they need to spend.



Building Name:
Central Shared Use Facility

Location:
10903 New Hampshire Ave,
Silver Spring, Maryland

Building Occupant:
Food and Drug Administration

Occupancy Function:
Main function: Business
Other functions: Assembly

Size: 126,000 sq. feet

Number of Stories:
1 below grade
3 above ground stories

Primary Project Team:
Owner: Food and Drug Administration
General Contractor:
AE/Engineering: Kling Lindquist – www.kling.us
RTKL Associates – www.rtkl.com
Civil Engineering: Greenhorne & O'Mara – www.g-and-o.com
Geotechnical/Soils: Schnabel Engineering Associates – www.schnabel-eng.com
Survey: A. Morton Thomas – www.amtengineering.com
Cost Estimating: Hanscomb Associates
Acoustics: Shen Milsom & Wilke, Inc. - www.smwinc.com
Food Service: Hopkins Foodservice Specialists - www.hopkins-fs-designers.com
Exterior Enclosure: Israel Berger & Associates, Inc. – www.ibany.com
Elevator Handling: Lerch Bates – www.learchbates.com
Traffic Engineering: Gorove/Slade – www.goroveslade.com
Wind Wake: Rowan, Williams, Davies, & Irwin - www.rwdi.com
Fire Protection: Rolf Jensen & Associates – www.rjagroup.com
Hardware Consultant – Gary Bogossian
LEED Review – Janet Harrison
Sustainable Engineering: Buro Happold - www.burohappold.com

Dates of Construction:
Under Construction, completion scheduled for May, 2006

Costs: $24,241,000

Project Delivery Method:
Design-Bid-Build

Overview

The Central Shared Use Facility (CSUF) is located in Silver Spring Maryland, on the Food and Drug Administrations campus. The 32,000 square foot, three story building spans 395 feet by 90 feet and is the central building on campus. It houses a gym, cafeteria, library, offices, and auditoriums. The building is directly connected to an existing building, and second story bridges will connect surrounding and future buildings. The entire north east façade, 395 foot long, is glass, which allows the lobby to be lit naturally during the day.

There are a few notable spaces within the building, including two spaces within the building that have not been designed yet. Located on the ground and third floor, these two spaces are shell spaces, and reserved for future renovation. The empty space on the ground floor will house a large data center which will connect every computer on the finished campus. The entire third floor is also an empty space, and is designed to house a library. The first floor lobby is a large atrium that extends all the way to a roof and is topped with a giant skylight.

The roof consists of two mechanical pads, skylights, and a green roof that covers the remaining portions of the roof. One of the main goals for this building was to receive a gold LEED rating, with 43 points. The green roof was a required design condition and necessary to achieve the LEED rating goals. However, after cost restricted the original design, the CSUF is expected to earn 38 LEED points and earn a Silver rating. The entire project was Design-Bid-Build and the total cost was $24,241,000.

Mechanical

There are seven air handling units located in the building. One supplies the ground floor; two supply the two stairwells; and the other four others supply the first two floors. Two more air handling units are located on the roof, and supply the indoor air handling units with outdoor air. Two more air handling units are planned to be placed on the third floor when the shell space is designed. Cooling coils are located in each air handling unit, and heating coils are located in the VAV boxes found throughout the building. Heat is also supplied to some spaces by finned tube radiators built into the floor. The bathrooms are exhausted directly, and the rest of the building is exhausted through two relief fans.

The cooling coils and heating coils are supplied with hot and cold water by a Primary/Secondary central plant located on the campus. The secondary pumps are located on the ground floor of the CSUF. Currently, the central plant contains three chillers, three boilers, and two natural gas generators. There is also a very small field of solar panels that power some of the campus's emergency power.

Lighting/Electrical

The main natural gas generator produces 4.8 megawatts. A backup generator can produce 2 megawatts. If the generators are disabled, PEPCO supplies backup and emergency power. The power distribution is both 480/277V and 208/120V.

Fluorescent bulbs are used to light the building. Recessed lamps are used in open areas such as the cafeteria and gym, while fluorescent panels are used to light the offices. There is emergency lighting throughout the building.

Structural

See the Structural Analysis section.

Fire Protection

The Shared Use Facility is fully sprinkled. The structural frame is has a 2 hour fire rating. If an interior column is not supporting a roof, it only has a 1 hour fire rating. The bearing exterior walls have 2 hour fire protection, as do the bearing interior walls. Nonbearing walls are rated for 1 hour if on the exterior and dependant on the occupancy elsewhere. All of the floors have a 2 hour fire rating. The roof is rated for 1 hour. The corridor walls along egress routes that are fully sprinkled do not have any fire rating. For the business occupants of the CSUF, the longest distance of egress traveled is 300 feet. The assembly occupants have an egress distance of only 200 feet.

Green Roof

The components of the Green roof help retain water, drain water, and protect the roof deck. In order from the Roof deck and up, the components are listed below.

1. Roof Membrane
2. Root Barrier
3. Insulation
4. Water Retention Mat
5. Drainage Layer
6. Filter Fabric
7. Soil
8. Vegetation

The roofing membrane assures that there will be no leaks onto the roof deck. To make this possible, the membrane is seamless, and installed by trained applicators. The root barrier prevents the vegetations' roots from penetrating the roof membrane. A water retention mat is used to help the roof retain water, to provide the vegetation with enough water to grow. The drainage mat allows the excess water to be drained from the roof, faster than conventional drainage methods. Once the garden roof is completely saturated, the remaining water will be drained off. The soil of the garden roof is not ordinary garden soil. Instead, it consists of native soil with organic additives. The soil itself is dense enough to resist wind loads that the roof will encounter. This prevents the garden roof from blowing away. The vegetation is not normal grass or sod. Instead, it is a mix of sedum, specifically Sedum album, Sedum reflexum, and Sedum sexangulare. These plants do not require mowing, and are very low maintenance.

Goals

There are two goals for this report. The first goal is to design and simulate a VAV system for the third floor space in the CSUF. The second goal is to use the simulated VAV system to analyze the affects of a green roof. The specific benefits of the green roof that are analyzed include water quantity control, water quality control, energy consumption, the LEED point system, structural support, and costs.

A VAV system was chosen to be the basis for the design because the designated space in CSUF is already designed for one. There are two mechanical rooms available that have cold water and electrical hook-ups available for air handling units. VAV systems are also very common, so the results of this report could be compared to other existing conditions on another project.

Green roofs are a growing technology, but there is not much information about the energy savings and benefits associated to them. Every benefit and cost of a green roof is directly related to the size of a green roof. The goal of this report is to record each benefit, or cost, associated with a green roof as a "benefit amount/square foot of green roof." By looking at differently sized green roofs, an optimum size for the green roof can be found.

Procedure

To design and simulate the VAV system, Trane's Trace program was used. The same design conditions as the CSUF were used, and the same equipment that was used throughout the rest of the building was used in the space as well. The space conditions of a library were used, and the amount of outdoor air supplied to the space was determined in accordance with ASHRAE Std. 62.1.2004. To simulate the green roof, the R-value of the soil was added to the R-value of the roof that Trace simulated. The manufacturer, Hydrotech, estimated their roof had an insulation value of R5 per inch of soil, which brought the roofs total R-value up to around R31. Other studies have shown similar results, calculating the R-value of soil to be from 17-38 (Sonne).

After the VAV system was designed to the existing conditions, it became the basis of comparison to the modified design conditions. To calculate the change in benefits compared to the area of green roof, the green roof was slowly reduced in size by increments of about 5%.

The existing green roof for the CSUF covers 66% of the total roof area. In each non design condition, the size of the green roof was reduced to first 60%, and then by 5% for each additional run, all the way down to 30%. Including the design, there are eight different designs in which each benefit was analyzed. The space was simulated for the summertime only, because past research has found that the green roof is less effective for heating loads than cooling loads, usually by a significant amount (Liu).

Since only the library was being simulated, the area for the library and not the entire roof was used in the TRANE simulations. The sections of the roof that were not simulated are occupied by the atrium skylight and stairwells. Each of these spaces are sealed off from the library, so the results of the calculations should remain the same.

Mechanical Analysis

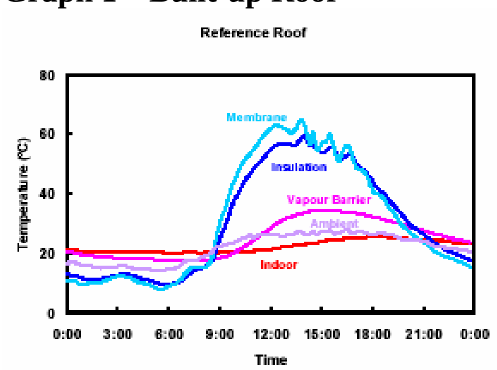
4.1 - Energy Savings

It is known that a green roof reduces the energy use of a building. The extra layer of insulation and reduced roof temperatures cause the heat flux through a thermal roof to be less then that of a standard built-up roof. Exactly how much is unknown, and has not been simulated. There have been many sustainability reports like Jeff Sonne's "Evaluating Green Roof Energy Performance" which evaluate existing green roofs with that of a standard roof. The reports always indicate that the heat flux through a green roof is less, but the amount varies. Some report a green roof will reduce the average heat flux through a roof by about 18% while others have reported as high as 47%-90%. (Sonne, Liu)

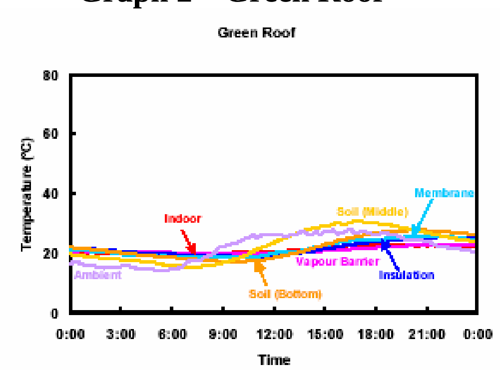
Since the CSUF has not been built and there is no existing load data, energy savings due to the green roof had to be estimated. To estimate these energy savings, Trane's TRACE700 program was used. This program simulated the green roof as an extra layer of insulation. Hydrotech provided estimates of their green roofs insulation value (R-value) and Trace's data on built-up roofs was used to estimate the R-value of the standard roof. The standard roof had an R-value of 17, and the total R-value of the standard roof and green roof was about 32. By changing the areas of the extra insulation, the differently sized green roofs were simulated.

One drawback to using TRACE700 is that the program assumes the absorption value and reflectance of the roof. Aside from adding an extra layer of insulation on a roof, a green roof also prevents the sunlight from contacting the roof membrane. This results in an average temperature of a green roof being significantly less during the course of a summer day than that of a built-up roof. The shortcomings of Trane's program will actually cause conservative results. The program is simulating a roof with extra insulation; however the temperature of the insulation will be that of a normal built-up roof. The temperature of the insulation of a green roof is significantly less.

Graph 1 – Built-up Roof



Graph 2 – Green Roof



Graph 1 and 2 represent the temperatures of a built-up roof and green roof respectively. The time graphed is the course of an entire day in a summer month, when the temperatures would be the greatest. Not only is the maximum temperature of the green roof reduced, the minimum temperature during the nighttime hours is higher than that of the standard roof. These graphs were taken from a study done by the National Research Council of Canada.

TRACE estimated that the yearly electrical consumption of the CSUF without a green roof was 516,500 kWh. Table 2 lists the results of the simulation. The electrical consumption listed is the reduced amount of consumption. For complete data, see Appendix A.

Table 2 – TRACE results

Green Roof (%)	Total Cooling Load (ton)	On-Peak Electrical Consumption Decrease (kWh)
66 – Design	105.9	32,475
60	109.2	29,035
55	112.0	26,178
50	114.8	23,095
45	117.7	20,200
40	120.5	17,609
35	123.6	15,189
30	126.4	12,055

The results listed in Table 2 indicate that the green roof did not have a substantial effect on the electrical consumption of the CSUF; only reducing the electrical consumption by about 7%. Other published papers that studied the effects of a green roof have indicated that electrical loads (kWh) were decreased anywhere from 17%-75%. (Lifecycle; Liu) The results calculated by TRACE were expected to be conservative because of the programs limitations. Another reason why the energy saves are estimated to be less is that there are skylights throughout the library. Other projects studying green roofs have studied buildings that were completely covered by a green roof.

Table 2 can be used to find the 'Benefit Savings per area of green roof' for Cooling Load, and Electrical Consumption.

For every 265 square feet (1%) of the roof that is green, there a

- 0.5% (0.6 tons) DECREASE in the Total Cooling Load
- 0.1% (626 kWh) DECREASE in the On-Peak Electrical Consumption

If data from existing projects were used to estimate the reduced energy load, a reduction of 50% could be assumed for the designed green roof condition covering 66% of the roof. A reduction of 50% seems to fall in the middle of other estimates done on different buildings. For the cost analysis of the green roof in Section 6, a simulated energy savings with the data above will be compared to an estimated energy savings using an energy consumption load reduction of 50%.

4.2 - Sizing Mechanical the Mechanical System

The type of mechanical system designed to supply the library was a standard VAV system. Not only are VAV systems the most common in the United States, existing mechanical equipment was designed to accommodate for a third floor VAV system. A VAV system is the most economical choice because the existing equipment will be utilized, and it will be comparable other green roof projects.

Similar to the other floors, the third floor contains a north and south mechanical room. Each room is approximately 25 feet by 16 feet with a 17' ceiling. Electrical and chilled water hook ups have already been designed to connect to an indoor air-handling unit. Each unit will be supplied with outdoor air from an existing rooftop air-handling unit. Each unit will also house a cooling coil supplied with chilled water pumped from three existing secondary pumps located in the basement of the building.

The VAV system designed for the 3rd floor must meet three design requirements.

1. Physical Size
2. Cooling Capacity
3. Cooling Coil Flow Restrictions

Solution Custom air-handling units from York were used throughout the rest of the building, so the same units were used for the 3rd floor.

After viewing the indoor air-handling units, it was determined that the physical size requirements for the air-handler's would not be a problem. The largest air-handler they supply is 12 feet by 17 feet by 10 feet (height).

The Trace results were used to determine the required cooling capacity for each design and are outlined in Table 3. The 0% green roof is a built-up roof.

Table 3 – Mechanical Equipment Sizes

Green Roof [%]	Peak Cooling Load [ton]	Supply Air Quantity [cfm]	Air Handling Unit Sizes [cfm]
0 - Built-Up	143.4	57,570	30,500
30	126.4	45,420	26,500
35	123.6	43,469	22,500
40	120.5	39,626	
45	117.7	37,796	19,500
50	114.8	35,979	
55	112.0	34,247	
60	109.2	32,534	16,500
66 - Design	105.9	30,493	

The three existing pumps in the basement of the CSUF each pump 460 gpm. The existing mechanical equipment in the building requires 1000 gpm at peak conditions. This means that the third pump is not being used as a backup, and that there is an available 380 gpm for the two 3rd floor air-handling units. If the designed cooling coils require more than this amount, another pump would need to be added to the system, and extra piping would be required. The cost of another pump and piping would be unacceptable.

The volumetric rate of water that need to be supplied to each cooling coil was found using Equation 1.

$$Q = m * cp * (\text{delta } T) \qquad \text{Eq. (1)}$$

Where:

cp specific heat of water (1.0003 Btu/(lb-F))
delta T change in water temperature (20°F)
m mass flow rate (lb/hr)
p density of water (62.41 lb/ft^3)
Q cooling load (Btu/hr)

The entering and leaving temperature's of water in the cooling coil are 59°F and 39°F respectively. The density and specific heat of water are at the condition of 49°F, the average temperature of water passing through the coil.

Table 4 – Required Amount of Chilled Water

Green Roof [%]	Cooling Load [ton]	Water Quantity [gpm]
0 – Built Up	143.4	171.829
30	126.4	151.4588
35	123.6	148.1037
40	120.5	144.3891
45	117.7	141.034
50	114.8	137.5591
55	112.0	134.204
60	109.2	130.8489
6 - Design	105.9	126.8946

The results in Table 4 conclude that there will be no problem supplying chilled water to any size air handling unit. It should be noted that even though the 3rd pump will be required at peak load conditions, the amount of time the 3rd pump will be required to run at off-design conditions is increased as the size of the green roof decreases.

4.3 - Water Quality

When it rains, the rainwater either evaporates, or drains into the ground, entering the underground water. When rainwater hits a roof, it is drained off the roof, and dumped into a storm water system. Typically, the water will pick up toxins as it drains from the roof. This introduces a need for a storm water filter system, which will filter out the toxins in the storm water, before it is introduced back into the ground water. Two common types of filters used are underground sand filters, and bio-retention filters.

Sand filters are large concrete tanks filled with fine aggregate sand, and buried underground. The storm water enters the top of the tank, and gravity forces the water through the fine aggregate sand. As the water flows through the sand, the toxins are left behind. The whole process is biological, and requires no pressurization.

Bio-Retention filters, also known as Rain Gardens, also reduce the amount of toxic water that flows underground, but use a different method. Instead of filtering the toxins out with sand, the bio-retention filter will retain the water. Then, the water is either absorbed by the plants, or slowly percolates. The main disadvantage of rain gardens is the coverage area of the filter. Most property owners do not want to set aside their property for a filter, when a sand filter could be used instead. However, since the amount of excavation needed to install a rain garden is significantly less then a sand filter, they are a lot less expensive.

The amount of quality control needed on a project is directly related to the impervious area of the roof and parking lots on the site. According to Greenhorne and O'mara, the civil engineering design firm for the project, 3,000 sq. ft. of quality control is required for every impervious acre. Green roofs reduce the amount of impervious acres on a roof, and significantly reduce the amount of quality control required.

Typically, if a green roof is placed on the entire roof, there is no quality control needed. The Central Shared Use Facility does not contain any filter system because it was assumed that the green roof would cover the entire roof. It does in fact cover the entire flat roof; however, the actual area of the green roof covers only about 66% of the entire roof. The remaining roof area is made up of mechanical equipment and skylights. The amount of quality control required for the design and off-design conditions are listed in Table 5. The amount of quality control needed is the size of the filter system required for proper cleaning.

Table 5 – Quality Control

Green Roof (%)	Concrete Area (sf)	Green Area (sf)	Impervious Area (acre)	Amount of Quality Control (sf)
66 - Design	9019	17506.5	0.21	621.11
60	10610	15915	0.24	730.72
55	11936	14588.75	0.27	822.06
50	13263	13262.5	0.30	913.40
45	14589	11936.25	0.33	1004.73
40	15915	10610	0.37	1096.07
35	17241	9283.75	0.40	1187.41
30	18568	7957.5	0.43	1278.75

4.4 - Water Quantity

Green roofs reduce the total amount of rainwater runoff of a roof because the soil and plants absorb a lot of the rain. According to Hydrotechs' calculations, the designed green roof can retain 67.9% of the annual rainfall. Typically, as the amount of runoff is reduced, the drain sizes and storm basins can also be reduced. This is not the case for green roofs however. Green roofs can only retain water until they become completely saturated, at which point all the rain that continue to falls will run off the roof as if there were no green roof. This is one reason why the roof drainage system and storm water basins cannot be reduced in size. The other is that storm basins are sized for the worst storm condition over the last 30 years, so typically, they are oversized for safety purposes to prevent flooding. Even though the roofing equipment cannot be reduced in size due to the quantity control provided by a green roof, there are LEED benefits related to the amount of runoff reduced by a green roof.

4. 5 - LEED Ratings

Garden roofs are being applied to LEED projects because they have the ability to add multiple LEED points to a project. They help with storm water management, urban heat islands, efficient landscaping, and construction materials.

To gain a LEED point in storm water management, the rate and quantity of storm water runoff must be reduced by at least 25%. The annual Precipitation and estimated runoff values were supplied by the manufacturer, who used a 30-Year Average Monthly Precipitation record for the area of Montgomery Country, MD.

Table 6 – Runoff Reduction Estimations

Green Roof (%)	Annual Precipitation (gal)	Total Runoff (gal)	Runoff Reduction (%)
66	819,808	424,637	48
60	819,808	453,108	45
55	819,808	476,835	42
50	819,808	500,562	39
45	819,808	524,288	36
40	819,808	548,051	33
35	819,809	571,741	30
30	819,808	595,468	27

Another benefit a green roof offers is the reduction of the Heat Island Effect. The temperature of a green roof is much lower, and fluctuates less compared to that of a normal black roof. To earn one LEED point, a vegetated roof that covers at least 50% of the entire roof must be installed.

These two LEED points are almost guaranteed when a green roof is constructed. There are also other possible LEED points a green roof can help earn, but they are based on the type of green roof installed and the type of site conditions that exist. One is water efficient landscaping. Since the runoff from a green roof is considered clean, that rainwater can be used to irrigate the surrounding landscape. There are two possible LEED points available if there is no need to use potable water for irrigation. Green roofs can also help achieve two more points because the materials are used to construct the green roofs can be recycled materials. The Hydrotech roofs are constructed with a minimum amount of 25% recycled content. Green roofs can also help gain points by increasing the amount of Regional Materials used on the project. Once again, this is based more on the manufacturer of the green roof and the conditions of the project than just size of the green roof.

The CSUF is guaranteed two LEED points for the green roof installed at design. If the roof was reduced down to cover only 50% of the roof, they would still earn two points, but if reduced below 50% covering, one point would be subtracted. The green roof would need to be large enough to cover at least 30% of the roof to earn a point for storm water management.

Table 7 – LEED Point Summary

Green Roof (%)	Guaranteed LEED Points	Potential LEED Points
66	2	6
60	2	6
55	2	6
50	2	6
45	1	5
40	1	5
35	1	5
30	1	5

Depending on the needs of the owner, 6 LEED points may be very valuable, and will make up for the initial cost of the green roof. In the case of the CSUF, the initial design required the building to earn at least 40+ LEED points. After a slight cost reduction, the LEED point requirement was reduced to 38 points. It was deemed essential that the project must contain a green roof because of its LEED value.

Structural Analysis

5.1 - Existing Conditions

The CSUF is comprised of a concrete frame, with concrete slab floors. On the third floor there are two type of columns used to support the roof. As illustrated in Figure 1, the columns along the west wall are square, with a side length of 24" and the rest of the columns are circular with a diameter of 30". For the third floor, the beams are 44 by 26 inches. An 8 inch slab rests on top of the beams and the floor to floor height for the 3rd floor is 19 feet. The circular columns were reinforced with 6#10 rebar, and the square columns were reinforced with 8#11 rebar. Columns A1 and A2 are designed around the stairwell, and were not considered in the analysis.

The column with the largest bay area and load was used to size the existing columns. For the circular columns, the largest bay area, located on column B8 is 646 sq. ft. Column C8 is the square column with the largest bay area equaling 366 sq. ft. The roof design dead load was 62.22 lb/sf. The snow load was 0.02 lb/sf. The live load was 0.15 lb/sf. These were the loads I used in my redesign calculations.

The original green roof can be seen in Figure 2. The gap between columns B4 through B7 and C4 through C7 is due to a mechanical pad that supports an air handling unit and relief fan. These columns were not downsized because even though the green roof around them was removed, they still need to support the mechanical pad. The other gaps in the green roof are due to skylights and exhaust fans.

All the circular and square columns are the same size. This helps ease the construction process because the contractor can use the same formwork for different columns, and will not need to worry about placing the wrong size column in the wrong place.

Figure 1 – Typical Framing Plan (North Wing)

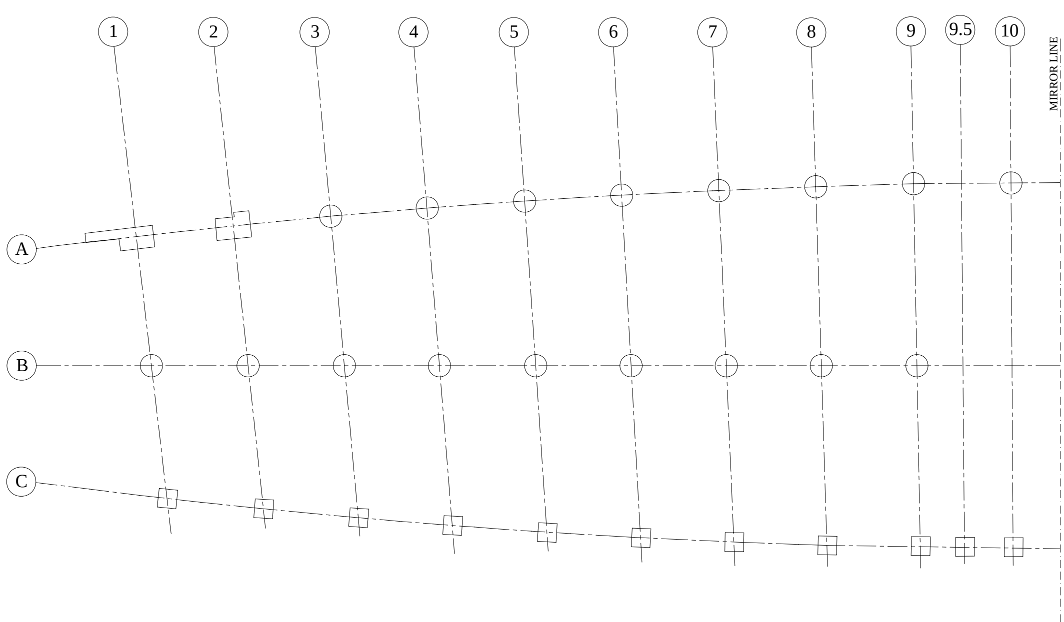
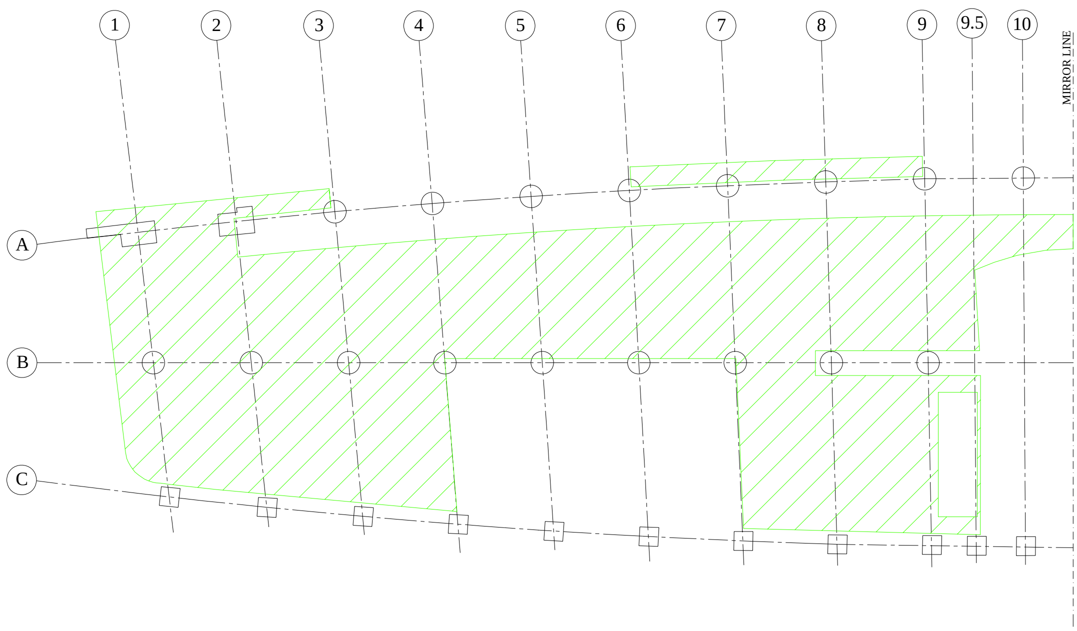


Figure 2 – Original Green Roof Coverage Area (North Wing)



5.2 - Redesign Procedure

As the green roof is reduced in size, some of the columns' dead loads were also reduced. Even though the green roof was reduced by small increments, every reduction was done to the same area, so that columns were able to be downsized faster. This can be seen in the Structural Appendix Section, Figures 1 to 7. To keep the ease of the construction process the same, the columns were only reduced in size to their minimum, meaning that only after the green roof was removed from the columns' entire bay area, was it reduced in size. This means that there are now two differently sized circular columns, and 2 differently sized square columns. The smaller columns will be placed starting on the north wing, while the large columns will be placed on the south wing. Even though there are 4 different types of columns, the ease of construction should still be the same.

To calculate the reduced load, the weight of the green roof was subtracted from the design dead load listed above. The weight of the green roof was calculated using data supplied by the manufacturer (Table B.1). The following equation was used to calculate the reduced force on each column.

$$\text{Total Load} = (1.6)\text{Live Load} + (1.2)\text{Dead Load} + (0.5)\text{Snow Load} \qquad \text{Eq. (2)}$$

ENERCALC, a program used to size columns was used to calculate the size for a column with the reduced force. An example of the calculations can be found in Appendix B.

5.3 - Redesign Results

The results are shown in Table 8. Table 8 also shows the difference between the large and small columns.

Table 8 – Designed and Redesigned Column Information

	Large Circular Column	Small Circular Column	Large Rectangular Column	Small Rectangular Column
Size	30" Diameter	14" Diameter	24"x 24"	12"x 12"
Reinforcement	6 #10	8 #8	8 #11	8 #6
CY of Concrete	3.45	0.75	2.81	0.71
Lbs of Steel	491	406	808	286

Figures B.1 to B.7 (Located in Appendix B) illustrate the columns that can be reduced in size to the small column after the green roof was removed. Table 9 shows the number of columns used in each design.

Table 9 – Number of Columns Used in Design and Redesign

Green Roof (%)	Large Circular Columns	Small Circular Columns	Large Rectangular Columns	Small Rectangular Columns
66 - Designed	34	0	20	0
60	34	0	20	0
55.	33	1	19	1
50.	32	2	18	2
45	29	5	17	3
40	29	5	15	5
35	27	7	15	5
30	21	13	15	5

First Cost Analysis

6.1 - Material and Labor

Built-up flat roofs are very cheap. RS Means estimates the costs of a typical built-up roof around $2 per square foot.

There have been many reports estimating the cost of green roofs throughout the US. There is a wide range, and the number is dependant on the type of project. RS Means could not be used to estimate the cost of a green roof because there is not enough data to accurately portray the market. One Google search will yield price ranges from $10-$30 dollars per square foot. For this report, it was assume that cost of the green roof was $14 per square foot. This includes all the material, labor, and instillation costs. A Green roof built in Washington DC estimated the costs of their roof to $14.43/sf. Since the project was a retrofit, I reduced the price by a small amount.

Using these numbers, the difference between a green roof and a built-up roof is an increase of $12 per square foot.

6.2 - Structural Costs

RS Means was used to estimate the material and labor costs of the four different types of columns used in the redesign. The information used is shown in Table 10. A location factor of 0.897 for Silver Spring Maryland was used. There was no time factor applied because the cost data is from 2006.

Table 10 – RS Means Data (2006)

RS Means Construction Cost Data 2006				
Type	Crew	Daily Output	Unit	Total Cost (Material + Labor Costs)
Formwork in place - 14" Diameter Round Fiber Tube	C1	145	LF	$10.43
Formwork in place - 30" Diameter Round Fiber Tube	C1	125	LF	$19.00
Formwork in place - 12" x 12" Job Built Plywood	C1	180	SFCA	$5.48
Formwork in place - 24" x 24" Job Built Plywood	C1	190	SFCA	$8.19
Reinforcement in place - #3 - #7 Column	4Rdm	2.3	ton	$1,700.00
Reinforcement in place - #8 > Column	4Rdm	1.5	ton	$1,405.00
Cast in place Concrete Mix - 3000psi	-	-	CY	$87.00
Column in place - 14" Diameter	C14A	26.23	CY	$564.75
Column in place - 30" Diameter	C14A	63.45	CY	$351.25
Column in place - 12" x 12"	C14A	11.96	CY	$960.50
Column in place - 24" x 24"	C14A	23.66	CY	$537.50

Even though the smaller columns were about half the size, the cost savings for installation and material were greater than that amount. The total cost of each column is:

Large Circular Column (30” Diameter) - $1,992
Small Circular Column (14” Diameter) - $875
Large Rectangular Column (24” x 24”) - $3,203
Small Rectangular Column (12” x 12”) - $1,253

By comparing these prices to Table 9, the structural savings was calculated for each off design condition. Obviously, as the green roof is decreased in size, the structural costs decrease. Even though the relation between the size of the green roof and the structural costs were not perfectly linear, the average additional structural support ended up costing about an additional $2.50 per square foot.

6.3 - Bio-Retention System Costs

Greenhorne and O’mara, the civil engineering design firm in charge of the project was able to supply an estimated cost of $30,000 per impervious acre of roof for a bio-retention. This number is their average cost of the system from all their past projects. They were also able to estimate the cost of a sand filter system to be about twice as much compared to that of a rain garden. These estimates are only useable for impervious areas of about 0.3 acres and greater. Obviously, if the impervious area was only 0.1 acres, it would cost more then $1,000 to install a bio-retention system. It was estimated that a minimum cost of a bio-retention system is around $5,000.

The location of the Central Shared Use Facility allows room for a bio-retention system. For cost analysis, it was assumed that a rain garden was already in place, and would only need to be expanded. By adding the green roof, the building owner saved about $0.69 per square foot on a bio-retention system.

6.4 - Mechanical Systems

The air handling unit costs were estimated with RS Means 2006. At the time this report was posted, a representative for York could not be reached to estimate the costs of their units. The reduced size of the air handling units saved an average of $2.25 per square foot of Green Roof.

Table 11 – Additional First Costs

Green Roof (%)	Material/Labor ($)	Structural ($)	Bio-Retention ($)	Mech. Eq. ($)	Total ($)
66	209,880	43,725	-12,068	-39,353	202,184
60	190,800	39,750	-10,971	-35,775	183,804
55	174,900	36,438	-10,057	-32,794	168,487
50	159,000	33,125	-9,143	-29,813	153,170
45	143,100	29,813	-8,228	-26,831	137,853
40	127,200	26,500	-7,314	-23,850	122,536
35	111,300	23,188	-6,400	-20,869	107,219
30	95,400	19,875	-5,486	-17,888	91,902

Lifetime Cost Analysis

7.1 - Annual Operating Costs

The energy savings produced by a green roof provide some relief for the heightened cost. The central utility plant supplying the CSUF reported that they are currently paying $0.10/kWh. The initial cost of their electrical generation was only about $0.05/kWh, but the cost of gas has increased significantly over the last couple years.

Table 12 sums up the estimated and simulated energy savings. As noted in section 4.1, the estimated energy savings are the savings predicted by studies done on existing buildings which found a reduced energy cost of about 50% with a fully designed green roof. The simulated energy savings use the results calculated by TRACE700.

Table 12 – Annual Energy Cost Savings

Green Roof (%)	Simulated On-Peak Electrical Consumption Decrease (kWh)	Simulated Savings ($)	Estimated On-Peak Electrical Consumption Decrease (kWh)	Estimated Savings ($)
66	32,475	3,248	258,250	25,825
60	29,035	2,904	234,773	23,477
55	26,178	2,618	215,208	21,521
50	23,095	2,310	195,644	19,564
45	20,200	2,020	176,080	17,608
40	17,609	1,761	156,515	15,652
35	15,189	1,519	136,951	13,695
30	12,055	1,206	117,386	11,739

Table 12 shows that the energy savings calculated by TRACE are much lower than that seen in existing buildings. If the TRACE results are used, the estimated payback period is around 60+ years for the designed (66%) green roof. This is clearly not acceptable. When looking at the results from existing buildings, the estimated energy savings will yield a payback period of only 7-10 years for the designed green roof.

7.2 – Maintenance Costs

The maintenance cost of a green roof is a topic of controversy. There is no collected data on these costs, and some people claim that a green roof requires zero maintenance. To estimate the costs of maintaining a green roof, I compared the green roof to a garden. Since the growing material is not sod, but instead small plants, no mowing is required. However, there may be small weeding, and watering necessary. It was assumed that one person would spend about 5 hours a week maintaining a green roof. This covered watering, weeding, and the time spent walking around the roof to check on it. This would only be done about 5 months out of the year. This is because during the winter months and periods of no growth, there would be no need for watering or weeding. The location of the CSUF is in Silver Spring Maryland, right outside of DC, so the estimated cost of the worker was $15 per hour. These assumptions calculated an annual maintenance cost of $1500.

To estimate the maintenance of a built-up roof, the same process was used. It was estimated that the same man would be hired to check the roof, but would need to do so 10 months over the course of a year. January and February were not counted because most likely snow will be covering the roof in those months and it would be impossible to check the roof. It was also assumed that the roof would only need to be repaired or worked on once a month instead of once a week. However, additional materials would be required to repair a crack in the roof, so this material cost was estimated at $10. The cost of the salary of the worker was assumed to be the same. With these assumptions, the annual maintenance cost was also equal to $1500.

Even though the annual maintenance costs of a green roof and built-up roof are probably the same, one benefit of a green roof is that the roof membrane is protected. This increases the lifespan of the roof itself. The lifespan of a built-up roof is about 15 years. The lifespan of a green roof is about the lifetime of the building itself. This means that every 12 years, an existing built-up roof will need to be completely replaced.

By combining the estimated energy savings and the lifetime savings of a green roof compared to a built-up roof, it can be estimated that the buyback period for a green roof is probably less than 10 years. Therefore, green roofs are very reasonable investments.

Mechanical

It is clear that there are many benefits associated with green roofs, but the most notable benefits are related to storm water management and other civil engineering concerns. Green roofs are marketed to reduce runoff and increase the runoff quality. Manufacturers are aware that the green roofs can reduce a building's cooling load; however, there is no easy way to predict the amount of energy saved.

Numerous studies have predicted energy savings, but the results vary. The energy savings calculated by TRACE are much smaller compared to energy savings reported by existing buildings. The program does not recognize that the increased insulation is from a green roof and cannot model it properly. I think more research is needed before a green roof can be accurately modeled to predict the energy savings associated with them. There has been some consistency between every study, including this simulation, and that is that there will be a reduction in the cooling load. In today's energy depleting market, I think it is important that every energy conservation method should be utilized in design.

The main reason the CSUF was designed with a green roof is because it is known that green roofs reduce the energy consumption of the building. Even though the exact amount is unknown, and cannot be known until the project is built, the government is willing to spend the extra money to cut down on energy consumption. Today's energy crisis will only become worse in the future, and the government is already spending extra money to help reduce energy.

Structural

The green roof adds a significant amount of weight to the roof structure. In general, a green roof can require the column dimensions to double. As seen above, no direct relation exists between the size of the green roof and the number of columns that would need to be resized.

As discussed in the mechanical analysis, the structural difference of this project cannot be compared with any other project. The number of columns in need of resizing depends on the structural system and location of the green roof.

Cost

The first cost of a green roof is more expensive mostly because the material and labor costs are so much higher compared to that of a built-up roof. The cost for additional structural support and savings for mechanical systems and drainage are almost equal. This means that as green roofs become more popular in the US and they are manufactured easier, the extra first cost of a green roof will be significantly less.

It has been reported that the maintenance cost of a green roof is much lower than that of a built-up roof. (Liu) Although my assumptions estimated they are probably around the same, the differences between the lifetime costs of the green roof help payback the additional first cost. The operating cost savings will also increase as the price of energy increases. This was a main concern for the owner of the CSUF and is one of the reasons why a green roof was required. There are also tax breaks credited to building owners with a LEED certified building. The green roof on the CSUF is worth at least 2 credits and possibly more depending on the rest of the project.

Architectural Aspects

Although not discussed in the report, green roofs offer great architectural value. The CSUF is in the center of the FDA's campus and will be surrounded by many taller buildings. The aesthetics of a building may not seem important in an energy use or cost analysis, but the aesthetics of the building will determine whether the building is built or not.

Application of the results

I do not think these results can be compared with other green roof projects, or can be used to analyze how a green roof will affect a future building. Most of the variables in the analysis are project specific; however, the following facts are common to green roofs.

- Currently, the industry allows a green roof to take the place of a water quality filtration system.
- Green roofs can reduce the amount of rainwater runoff, and reduce the temperature gradient through the roof. Consequently, two LEED points can be earned by just building a green roof.
- The structure required to support a green roof is significantly larger and more expensive compared to that of a normal roof.
- The cooling load of a building can be decreased, but the amount is hard to determine. This reduced cooling load means there will be a reduced energy usage during the summer months.

The fact that a green roof can produce energy savings means that there is some value in the technology. This report analyzed for a VAV system, but other systems such as a DOAS system can utilize the reduced cooling load. A DOAS system with a reduced cooling load means the radiant cooling panels could be reduced in size. Since these panels are the most controversial design aspect of the system, a reduction in their size would be beneficial.

Conclusion

Green roof technology is new to the United States, and there is not a lot of information on how it can help conserve energy. Right now, the industry is taking advantage of the lack of information. For instance, the design for the Central Shared Use Facility did not include any water quality control filters. This is because there was a green roof covering the entire roof except where skylights and mechanical equipment was located. Even though 34% of the designed roof is impervious, it was assumed that the water that hit the impervious area would just absorb into the green roof and become cleaned that way. This is not true, because a 6" barrier exists between the edge of the green roof and any obstacles.

The CSUF benefits the most from the designed green roof of 66%. This design has the highest upfront cost, but the most energy savings. There does not seem to be a most economical/beneficial size of a green roof in terms of percent covering of a roof. The most beneficial green roof design must be determined by the amount of money an owner can spend on its first cost. If the owner can spend to make the entire roof green, then that design will result in the most savings. If an owner can only cover 30% of his roof, there will still be energy savings although at a reduced rate.

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Appendix
A

TRACE Results

Zone Checksums
By ae

Library 66

COOLING COIL PEAK / CLG SPACE PEAK

Peaked at Time: Mo/Hr: 7 / 14 — Outside Air: OADB/WB/HR: 91 / 77 / 121

CLG Space Peak: Mo/Hr: 7 / 13 — OADB: 89

	Space Sens. + Lat. Btu/h	Plenum Sens. + Lat Btu/h	Net Total Btu/h	Percent Of Total (%)	Space Sensible Btu/h	Percent Of Total (%)
Envelope Loads						
Skylite Solar	194,545	0	194,545	15.31	203,491	32.75
Skylite Cond	0	9,976	9,976	0.79	0	0.00
Roof Cond	0	25,680	25,680	2.02	0	0.00
Glass Solar	154,093	0	154,093	12.13	158,600	25.52
Glass Cond	61,406	0	61,406	4.83	56,217	9.05
Wall Cond	18,773	3,911	22,684	1.79	17,838	2.87
Partition	0		0	0.00	0	0.00
Exposed Floor	0		0	0.00	0	0.00
Infiltration	0		0	0.00	0	0.00
Sub Total ==>	428,817	39,567	468,384	36.87	436,145	70.18
Internal Loads						
Lights	27,151	108,602	135,753	10.69	27,151	4.37
People	212,135		212,135	16.70	129,933	20.91
Misc	0	0	0	0.00	0	0.00
Sub Total ==>	239,286	108,602	347,888	27.39	157,083	25.28
Ceiling Load	29,592	-29,592	0	0.00	28,198	4.54
Ventilation Load	0	0	449,476	35.38	0	0.00
Ov/Undr Sizing	0		0	0.00	0	0.00
Exhaust Heat		-31,232	-31,232	-2.46		
Sup. Fan Heat			35,795	2.82		
Ret. Fan Heat		0	0	0.00		
Duct Heat Pkup		0	0	0.00		
Reheat at Design			0	0.00		
Grand Total ==>	697,695	87,345	1,270,310	100.00	621,426	100.00

HEATING COIL PEAK

Mo/Hr: 13 / 1 — OADB: 17

	Space Peak Space Sens Btu/h	Coil Peak Tot Sens Btu/h	Percent Of Total (%)
Envelope Loads			
Skylite Solar	0	0	0.00
Skylite Cond	0	-39,456	5.22
Roof Cond	0	-48,894	6.46
Glass Solar	0	0	0.00
Glass Cond	-211,204	-211,204	27.92
Wall Cond	-33,365	-40,491	5.35
Partition	0	0	0.00
Exposed Floor	0	0	0.00
Infiltration	0	0	0.00
Sub Total ==>	-244,569	-340,045	44.96
Internal Loads			
Lights	0	0	0.00
People	0	0	0.00
Misc	0	0	0.00
Sub Total ==>	0	0	0.00
Ceiling Load	-43,130	0	0.00
Ventilation Load	0	-452,256	59.79
Ov/Undr Sizing	0	0	0.00
Exhaust Heat		45,520	-6.02
OA Preheat Diff.		0	0.00
RA Preheat Diff.		-9,590	1.27
Additional Reheat		0	0.00
System Plenum Heat		0	0.00
Grand Total ==>	-287,699	-756,371	100.00

TEMPERATURES

	Cooling	Heating
SADB	56.7	96.2
Plenum	78.5	62.9
Return	78.5	62.9
Ret/OA	81.7	23.0
Fn MtrTD	0.1	0.0
Fn BldTD	0.2	0.0
Fn Frict	0.7	0.0

AIRFLOWS

	Cooling	Heating
Vent	7,955	7,955
Infil	0	0
Supply	30,493	9,148
MinStop/Rh	9,148	9,148
Return	30,493	9,148
Exhaust	7,955	7,955
Rm Exh	0	0
Auxil	0	0

ENGINEERING CKS

	Cooling	Heating
% OA	26.1	87.0
cfm/ft²	1.15	0.34
cfm/ton	288.06	
ft²/ton	250.49	
Btu/hr·ft²	47.91	0.00
No. People	530	

COOLING COIL SELECTION

	Total Capacity ton	Total Capacity MBh	Sens Cap. MBh	Coil Airflow cfm	Enter DB °F	Enter WB °F	Enter HR gr/lb	Leave DB °F	Leave WB °F	Leave HR gr/lb
Main Clg	105.9	1,270.3	876.1	30,202	81.7	67.8	79.9	55.7	54.5	61.5
Aux Clg	0.0	0.0	0.0	0	0.0	0.0	0.0	0.0	0.0	0.0
Opt Vent	0.0	0.0	0.0	0	0.0	0.0	0.0	0.0	0.0	0.0
Total	105.9	1,270.3								

AREAS

	Gross Total	Glass ft²	Glass (%)
Floor	26,517		
Part	0		
ExFlr	0		
Roof	26,525	1,578	6
Wall	16,518	7,598	46

HEATING COIL SELECTION

	Capacity MBh	Coil Airflow cfm	Ent °F	Lvg °F
Main Htg	0.0	9,148	96.2	96.2
Aux Htg	0.0	0	0.0	0.0
Preheat	0.0	7,955	17.0	55.7
Humidif	0.0	0	0.0	0.0
Opt Vent	0.0	0	0.0	0.0
Total	-0.1			

MONTHLY UTILITY COSTS

By ae

Alternative: 1

Utility	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Total
					------- Monthly Utility Costs -------								
Electric													
On-Pk Cons. ($)	2,959	2,673	3,049	3,433	4,848	5,353	5,878	5,490	4,731	3,457	3,171	2,959	48,002
Monthly Total ($):	2,959	2,673	3,049	3,433	4,848	5,353	5,878	5,490	4,731	3,457	3,171	2,959	48,002

Zone Checksums

By ae

Library 60

COOLING COIL PEAK / CLG SPACE PEAK

Cooling Coil Peak — Peaked at Time: Mo/Hr: 7 / 14; Outside Air: OADB/WB/HR: 91 / 77 / 121

Clg Space Peak — Mo/Hr: 7 / 13; OADB: 89

	Space Sens. + Lat. Btu/h	Plenum Sens. + Lat Btu/h	Net Total Btu/h	Percent Of Total (%)	Space Sensible Btu/h	Percent Of Total (%)
Envelope Loads						
Skylite Solar	228,834	0	228,834	17.46	239,357	36.47
Skylite Cond	0	11,837	11,837	0.90	0	0.00
Roof Cond	0	26,620	26,620	2.03	0	0.00
Glass Solar	154,093	0	154,093	11.76	158,600	24.16
Glass Cond	61,406	0	61,406	4.68	56,217	8.57
Wall Cond	18,773	3,928	22,701	1.73	17,838	2.72
Partition	0		0	0.00	0	0.00
Exposed Floor	0		0	0.00	0	0.00
Infiltration	0		0	0.00	0	0.00
Sub Total ==>	463,107	42,385	505,492	38.57	472,011	71.92
Internal Loads						
Lights	27,151	108,602	135,753	10.36	27,151	4.14
People	212,135		212,135	16.18	129,933	19.80
Misc	0	0	0	0.00	0	0.00
Sub Total ==>	239,286	108,602	347,888	26.54	157,083	23.93
Ceiling Load	28,665	-28,665	0	0.00	27,234	4.15
Ventilation Load	0	0	449,504	34.29	0	0.00
Ov/Undr Sizing	0		0	0.00	0	0.00
Exhaust Heat		-30,254	-30,254	-2.31		
Sup. Fan Heat			38,120	2.91		
Ret. Fan Heat		0	0	0.00		
Duct Heat Pkup		0	0	0.00		
Reheat at Design			0	0.00		
Grand Total ==>	731,057	92,069	1,310,750	100.00	656,328	100.00

HEATING COIL PEAK

Mo/Hr: 13 / 1; OADB: 17

	Space Peak Space Sens Btu/h	Coil Peak Tot Sens Btu/h	Percent Of Total (%)
Envelope Loads			
Skylite Solar	0	0	0.00
Skylite Cond	0	-46,175	6.03
Roof Cond	0	-50,198	6.55
Glass Solar	0	0	0.00
Glass Cond	-211,204	-211,204	27.56
Wall Cond	-33,365	-40,455	5.28
Partition	0	0	0.00
Exposed Floor	0	0	0.00
Infiltration	0	0	0.00
Sub Total ==>	-244,569	-348,032	45.41
Internal Loads			
Lights	0	0	0.00
People	0	0	0.00
Misc	0	0	0.00
Sub Total ==>	0	0	0.00
Ceiling Load	-45,083	0	0.00
Ventilation Load	0	-452,256	59.01
Ov/Undr Sizing	0	0	0.00
Exhaust Heat		47,582	-6.21
OA Preheat Diff.		0	0.00
RA Preheat Diff.		-13,673	1.78
Additional Reheat		0	0.00
System Plenum Heat		0	0.00
Grand Total ==>	-289,652	-766,379	100.00

TEMPERATURES

	Cooling	Heating
SADB	56.9	94.6
Plenum	78.4	62.6
Return	78.4	62.6
Ret/OA	81.4	25.4
Fn MtrTD	0.1	0.0
Fn BldTD	0.2	0.0
Fn Frict	0.7	0.0

AIRFLOWS

	Cooling	Heating
Vent	7,955	7,955
Infil	0	0
Supply	32,534	9,760
MinStop/Rh	9,760	9,760
Return	32,534	9,760
Exhaust	7,955	7,955
Rm Exh	0	0
Auxil	0	0

ENGINEERING CKS

	Cooling	Heating
% OA	24.5	81.5
cfm/ft²	1.23	0.37
cfm/ton	297.85	
ft²/ton	242.76	
Btu/hr·ft²	49.43	0.00
No. People	530	

COOLING COIL SELECTION

	Total Capacity ton	Total Capacity MBh	Sens Cap. MBh	Coil Airflow cfm	Enter DB °F	Enter WB °F	Enter HR gr/lb	Leave DB °F	Leave WB °F	Leave HR gr/lb
Main Clg	109.2	1,310.8	916.5	32,164	81.4	67.5	79.0	55.8	54.6	61.8
Aux Clg	0.0	0.0	0.0	0	0.0	0.0	0.0	0.0	0.0	0.0
Opt Vent	0.0	0.0	0.0	0	0.0	0.0	0.0	0.0	0.0	0.0
Total	109.2	1,310.8								

AREAS

	Gross Total	Glass ft²	Glass (%)
Floor	26,517		
Part	0		
ExFlr	0		
Roof	26,523	1,857	7
Wall	16,518	7,598	46

HEATING COIL SELECTION

	Capacity MBh	Coil Airflow cfm	Ent °F	Lvg °F
Main Htg	0.0	9,760	94.6	94.6
Aux Htg	0.0	0	0.0	0.0
Preheat	0.0	7,955	17.0	55.8
Humidif	0.0	0	0.0	0.0
Opt Vent	0.0	0	0.0	0.0
Total	-0.1			

MONTHLY UTILITY COSTS

By ae

Alternative: 1

Utility	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Total
					------- Monthly Utility Costs -------								
Electric													
On-Pk Cons. ($)	2,959	2,673	3,104	3,461	4,872	5,377	5,907	5,512	4,755	3,558	3,208	2,959	48,346
Monthly Total ($):	2,959	2,673	3,104	3,461	4,872	5,377	5,907	5,512	4,755	3,558	3,208	2,959	48,346

Zone Checksums

By ae

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COOLING COIL PEAK / CLG SPACE PEAK

Cooling Coil Peak — Peaked at Time: Mo/Hr: 7 / 14; Outside Air: OADB/WB/HR: 91 / 77 / 121

Clg Space Peak — Mo/Hr: 7 / 13; OADB: 89

	Space Sens. + Lat. Btu/h	Plenum Sens. + Lat Btu/h	Net Total Btu/h	Percent Of Total (%)	Space Sensible Btu/h	Percent Of Total (%)
Envelope Loads						
Skylite Solar	257,448	0	257,448	19.15	269,286	39.28
Skylite Cond	0	13,405	13,405	1.00	0	0.00
Roof Cond	0	27,404	27,404	2.04	0	0.00
Glass Solar	154,093	0	154,093	11.46	158,600	23.14
Glass Cond	61,406	0	61,406	4.57	56,217	8.20
Wall Cond	18,773	3,941	22,714	1.69	17,838	2.60
Partition	0		0	0.00	0	0.00
Exposed Floor	0		0	0.00	0	0.00
Infiltration	0		0	0.00	0	0.00
Sub Total ==>	491,720	44,750	536,471	39.90	501,941	73.22
Internal Loads						
Lights	27,151	108,602	135,753	10.10	27,151	3.96
People	212,135		212,135	15.78	129,933	18.95
Misc	0	0	0	0.00	0	0.00
Sub Total ==>	239,286	108,602	347,888	25.88	157,083	22.91
Ceiling Load	27,956	-27,956	0	0.00	26,498	3.87
Ventilation Load	0	0	449,527	33.44	0	0.00
Ov/Undr Sizing	0		0	0.00	0	0.00
Exhaust Heat		-29,505	-29,505	-2.19		
Sup. Fan Heat			40,070	2.98		
Ret. Fan Heat		0	0	0.00		
Duct Heat Pkup		0	0	0.00		
Reheat at Design			0	0.00		
Grand Total ==>	758,962	95,892	1,344,450	100.00	685,522	100.00

HEATING COIL PEAK

Mo/Hr: 13 / 1; OADB: 17

	Space Peak Space Sens Btu/h	Coil Peak Tot Sens Btu/h	Percent Of Total (%)
Envelope Loads			
Skylite Solar	0	0	0.00
Skylite Cond	0	-51,745	6.68
Roof Cond	0	-51,293	6.62
Glass Solar	0	0	0.00
Glass Cond	-211,204	-211,204	27.27
Wall Cond	-33,365	-40,427	5.22
Partition	0	0	0.00
Exposed Floor	0	0	0.00
Infiltration	0	0	0.00
Sub Total ==>	-244,569	-354,669	45.79
Internal Loads			
Lights	0	0	0.00
People	0	0	0.00
Misc	0	0	0.00
Sub Total ==>	0	0	0.00
Ceiling Load	-46,591	0	0.00
Ventilation Load	0	-452,256	58.39
Ov/Undr Sizing	0	0	0.00
Exhaust Heat		49,174	-6.35
OA Preheat Diff.		0	0.00
RA Preheat Diff.		-16,738	2.16
Additional Reheat		0	0.00
System Plenum Heat		0	0.00
Grand Total ==>	-291,160	-774,489	100.00

TEMPERATURES

	Cooling	Heating
SADB	57.0	93.4
Plenum	78.3	62.5
Return	78.3	62.5
Ret/OA	81.2	27.3
Fn MtrTD	0.1	0.0
Fn BldTD	0.2	0.0
Fn Frict	0.7	0.0

AIRFLOWS

	Cooling	Heating
Vent	7,955	7,955
Infil	0	0
Supply	34,247	10,274
MinStop/Rh	10,274	10,274
Return	34,247	10,274
Exhaust	7,955	7,955
Rm Exh	0	0
Auxil	0	0

ENGINEERING CKS

	Cooling	Heating
% OA	23.2	77.4
cfm/ft²	1.29	0.39
cfm/ton	305.67	
ft²/ton	236.68	
Btu/hr·ft²	50.70	0.00
No. People	530	

COOLING COIL SELECTION

	Total Capacity ton	Total Capacity MBh	Sens Cap. MBh	Coil Airflow cfm	Enter DB °F	Enter WB °F	Enter HR gr/lb	Leave DB °F	Leave WB °F	Leave HR gr/lb
Main Clg	112.0	1,344.5	950.2	33,809	81.2	67.3	78.3	56.0	54.7	61.9
Aux Clg	0.0	0.0	0.0	0	0.0	0.0	0.0	0.0	0.0	0.0
Opt Vent	0.0	0.0	0.0	0	0.0	0.0	0.0	0.0	0.0	0.0
Total	112.0	1,344.5								

AREAS

	Gross Total	Glass ft²	Glass (%)
Floor	26,517		
Part	0		
ExFlr	0		
Roof	26,523	2,089	8
Wall	16,518	7,598	46

HEATING COIL SELECTION

	Capacity MBh	Coil Airflow cfm	Ent °F	Lvg °F
Main Htg	0.0	10,274	93.4	93.4
Aux Htg	0.0	0	0.0	0.0
Preheat	0.0	7,955	17.0	56.0
Humidif	0.0	0	0.0	0.0
Opt Vent	0.0	0	0.0	0.0
Total	-0.1			

MONTHLY UTILITY COSTS

By ae

Alternative: 1

Utility	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Total
					------- Monthly Utility Costs -------								
Electric													
On-Pk Cons. ($)	2,959	2,673	3,152	3,517	4,901	5,397	5,932	5,530	4,777	3,605	3,230	2,959	48,632
Monthly Total ($):	2,959	2,673	3,152	3,517	4,901	5,397	5,932	5,530	4,777	3,605	3,230	2,959	48,632

Zone Checksums

By ae

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COOLING COIL PEAK / CLG SPACE PEAK

	COOLING COIL PEAK				CLG SPACE PEAK	
	Peaked at Time: Mo/Hr: 7 / 14				Mo/Hr: 7 / 13	
	Outside Air: OADB/WB/HR: 91 / 77 / 121				OADB: 89	
	Space Sens. + Lat.	**Plenum Sens. + Lat**	**Net Total**	**Percent Of Total**	**Space Sensible**	**Percent Of Total**
	Btu/h	Btu/h	Btu/h	**(%)**	Btu/h	**(%)**
Envelope Loads						
Skylite Solar	286,056	0	286,056	20.76	299,209	41.86
Skylite Cond	0	14,986	14,986	1.09	0	0.00
Roof Cond	0	28,186	28,186	2.05	0	0.00
Glass Solar	154,093	0	154,093	11.18	158,600	22.19
Glass Cond	61,406	0	61,406	4.46	56,217	7.87
Wall Cond	18,773	3,953	22,726	1.65	17,838	2.50
Partition	0	0	0	0.00	0	0.00
Exposed Floor	0		0	0.00	0	0.00
Infiltration	0		0	0.00	0	0.00
Sub Total ==>	520,328	47,126	567,454	41.18	531,863	74.41
Internal Loads						
Lights	27,151	108,602	135,753	9.85	27,151	3.80
People	212,135		212,135	15.39	129,933	18.18
Misc	0	0	0	0.00	0	0.00
Sub Total ==>	239,286	108,602	347,888	25.24	157,083	21.98
Ceiling Load	27,290	-27,290	0	0.00	25,810	3.61
Ventilation Load	0	0	449,485	32.62	0	0.00
Ov/Undr Sizing	0		0	0.00	0	0.00
Exhaust Heat		-28,803	-28,803	-2.09		
Sup. Fan Heat			42,042	3.05		
Ret. Fan Heat		0	0	0.00		
Duct Heat Pkup		0	0	0.00		
Reheat at Design			0	0.00		
Grand Total ==>	786,904	99,635	1,378,066	100.00	714,757	100.00

HEATING COIL PEAK

Mo/Hr: 13 / 1
OADB: 17

	Space Peak Space Sens	**Coil Peak Tot Sens**	**Percent Of Total**
	Btu/h	Btu/h	**(%)**
Envelope Loads			
Skylite Solar	0	0	0.00
Skylite Cond	0	-57,284	7.32
Roof Cond	0	-52,394	6.70
Glass Solar	0	0	0.00
Glass Cond	-211,204	-211,204	26.99
Wall Cond	-33,365	-40,401	5.16
Partition	0	0	0.00
Exposed Floor	0	0	0.00
Infiltration	0	0	0.00
Sub Total ==>	-244,569	-361,283	46.17
Internal Loads			
Lights	0	0	0.00
People	0	0	0.00
Misc	0	0	0.00
Sub Total ==>	0	0	0.00
Ceiling Load	-47,990	0	0.00
Ventilation Load	0	-452,256	57.80
Ov/Undr Sizing	0	0	0.00
Exhaust Heat		50,650	-6.47
OA Preheat Diff.		0	0.00
RA Preheat Diff.		-19,533	2.50
Additional Reheat		0	0.00
System Plenum Heat		0	0.00
Grand Total ==>	-292,559	-782,422	100.00

TEMPERATURES

	Cooling	**Heating**
SADB	57.2	92.3
Plenum	78.3	62.3
Return	78.3	62.3
Ret/OA	81.0	28.9
Fn MtrTD	0.1	0.0
Fn BldTD	0.2	0.0
Fn Frict	0.7	0.0

AIRFLOWS

	Cooling	**Heating**
Vent	7,955	7,955
Infil	0	0
Supply	35,979	10,794
MinStop/Rh	10,794	10,794
Return	35,979	10,794
Exhaust	7,955	7,955
Rm Exh	0	0
Auxil	0	0

ENGINEERING CKS

	Cooling	**Heating**
% OA	22.1	73.7
cfm/ft²	1.36	0.41
cfm/ton	313.30	
ft²/ton	230.91	
Btu/hr·ft²	51.97	0.00
No. People	530	

COOLING COIL SELECTION

	Total Capacity		**Sens Cap.**	**Coil Airflow**	**Enter DB/WB/HR**			**Leave DB/WB/HR**		
	ton	MBh	MBh	cfm	°F	°F	gr/lb	°F	°F	gr/lb
Main Clg	114.8	1,378.1	983.8	35,473	81.0	67.2	77.7	56.1	54.8	62.1
Aux Clg	0.0	0.0	0.0	0	0.0	0.0	0.0	0.0	0.0	0.0
Opt Vent	0.0	0.0	0.0	0	0.0	0.0	0.0	0.0	0.0	0.0
Total	114.8	1,378.1								

AREAS

	Gross Total	**Glass**	
		ft²	**(%)**
Floor	26,517		
Part	0		
ExFlr	0		
Roof	26,524	2,321	9
Wall	16,518	7,598	46

HEATING COIL SELECTION

	Capacity	**Coil Airflow**	**Ent**	**Lvg**
	MBh	cfm	°F	°F
Main Htg	0.0	10,794	92.3	92.3
Aux Htg	0.0	0	0.0	0.0
Preheat	0.0	7,955	17.0	56.1
Humidif	0.0	0	0.0	0.0
Opt Vent	0.0	0	0.0	0.0
Total	-0.1			

MONTHLY UTILITY COSTS

By ae

Alternative: 1

Utility	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Total
					------- Monthly Utility Costs -------								
Electric													
On-Pk Cons. ($)	2,959	2,673	3,182	3,615	4,927	5,418	5,957	5,550	4,799	3,642	3,259	2,959	48,941
Monthly Total ($):	2,959	2,673	3,182	3,615	4,927	5,418	5,957	5,550	4,799	3,642	3,259	2,959	48,941

Zone Checksums

By ae

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COOLING COIL PEAK / CLG SPACE PEAK

Cooling Coil Peak — Peaked at Time: Mo/Hr: 7 / 14; Outside Air: OADB/WB/HR: 91 / 77 / 121

Clg Space Peak — Mo/Hr: 7 / 13; OADB: 89

	Space Sens. + Lat. Btu/h	Plenum Sens. + Lat Btu/h	Net Total Btu/h	Percent Of Total (%)	Space Sensible Btu/h	Percent Of Total (%)
Envelope Loads						
Skylite Solar	314,657	0	314,657	22.29	329,125	44.24
Skylite Cond	0	16,585	16,585	1.17	0	0.00
Roof Cond	0	28,972	28,972	2.05	0	0.00
Glass Solar	154,093	0	154,093	10.91	158,600	21.32
Glass Cond	61,406	0	61,406	4.35	56,217	7.56
Wall Cond	18,773	3,966	22,738	1.61	17,838	2.40
Partition	0		0	0.00	0	0.00
Exposed Floor	0		0	0.00	0	0.00
Infiltration	0		0	0.00	0	0.00
Sub Total ==>	548,929	49,523	598,452	42.39	561,780	75.51
Internal Loads						
Lights	27,151	108,602	135,753	9.62	27,151	3.65
People	212,135		212,135	15.03	129,933	17.46
Misc	0	0	0	0.00	0	0.00
Sub Total ==>	239,286	108,602	347,888	24.64	157,083	21.11
Ceiling Load	26,629	-26,629	0	0.00	25,131	3.38
Ventilation Load	0	0	449,517	31.84	0	0.00
Ov/Undr Sizing	0		0	0.00	0	0.00
Exhaust Heat		-28,106	-28,106	-1.99		
Sup. Fan Heat			44,111	3.12		
Ret. Fan Heat		0	0	0.00		
Duct Heat Pkup		0	0	0.00		
Reheat at Design			0	0.00		
Grand Total ==>	814,844	103,390	1,411,863	100.00	743,994	100.00

HEATING COIL PEAK

Mo/Hr: 13 / 1; OADB: 17

	Space Peak Space Sens Btu/h	Coil Peak Tot Sens Btu/h	Percent Of Total (%)
Envelope Loads			
Skylite Solar	0	0	0.00
Skylite Cond	0	-62,804	7.95
Roof Cond	0	-53,504	6.77
Glass Solar	0	0	0.00
Glass Cond	-211,204	-211,204	26.73
Wall Cond	-33,365	-40,378	5.11
Partition	0	0	0.00
Exposed Floor	0	0	0.00
Infiltration	0	0	0.00
Sub Total ==>	-244,569	-367,890	46.55
Internal Loads			
Lights	0	0	0.00
People	0	0	0.00
Misc	0	0	0.00
Sub Total ==>	0	0	0.00
Ceiling Load	-49,243	0	0.00
Ventilation Load	0	-452,256	57.23
Ov/Undr Sizing	0	0	0.00
Exhaust Heat		51,972	-6.58
OA Preheat Diff.		0	0.00
RA Preheat Diff.		-22,107	2.80
Additional Reheat		0	0.00
System Plenum Heat		0	0.00
Grand Total ==>	-293,812	-790,281	100.00

TEMPERATURES

	Cooling	Heating
SADB	57.3	91.3
Plenum	78.2	62.1
Return	78.2	62.1
Ret/OA	80.8	30.5
Fn MtrTD	0.1	0.0
Fn BldTD	0.2	0.0
Fn Frict	0.7	0.0

AIRFLOWS

	Cooling	Heating
Vent	7,955	7,955
Infil	0	0
Supply	37,796	11,339
MinStop/Rh	11,339	11,339
Return	37,796	11,339
Exhaust	7,955	7,955
Rm Exh	0	0
Auxil	0	0

ENGINEERING CKS

	Cooling	Heating
% OA	21.0	70.2
cfm/ft²	1.43	0.43
cfm/ton	321.24	
ft²/ton	225.38	
Btu/hr·ft²	53.24	0.00
No. People	530	

COOLING COIL SELECTION

	Total Capacity ton	Total Capacity MBh	Sens Cap. MBh	Coil Airflow cfm	Enter DB °F	Enter WB °F	Enter HR gr/lb	Leave DB °F	Leave WB °F	Leave HR gr/lb
Main Clg	117.7	1,411.9	1,017.6	37,219	80.8	67.0	77.1	56.3	54.9	62.2
Aux Clg	0.0	0.0	0.0	0	0.0	0.0	0.0	0.0	0.0	0.0
Opt Vent	0.0	0.0	0.0	0	0.0	0.0	0.0	0.0	0.0	0.0
Total	117.7	1,411.9								

AREAS

	Gross Total	Glass ft²	Glass (%)
Floor	26,517		
Part	0		
ExFlr	0		
Roof	26,523	2,553	10
Wall	16,518	7,598	46

HEATING COIL SELECTION

	Capacity MBh	Coil Airflow cfm	Ent °F	Lvg °F
Main Htg	0.0	11,339	91.2	91.3
Aux Htg	0.0	0	0.0	0.0
Preheat	0.0	7,955	17.0	56.3
Humidif	0.0	0	0.0	0.0
Opt Vent	0.0	0	0.0	0.0
Total	-0.1			

MONTHLY UTILITY COSTS

By ae

Alternative: 1

Utility	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Total
					------- Monthly Utility Costs -------								
Electric													
On-Pk Cons. ($)	2,959	2,673	3,234	3,640	4,955	5,439	5,983	5,570	4,820	3,681	3,314	2,959	49,228
Monthly Total ($):	2,959	2,673	3,234	3,640	4,955	5,439	5,983	5,570	4,820	3,681	3,314	2,959	49,228

Zone Checksums

By ae

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COOLING COIL PEAK / CLG SPACE PEAK

Cooling Coil Peak — Peaked at Time: Mo/Hr: 7 / 14; Outside Air: OADB/WB/HR: 91 / 77 / 121

Clg Space Peak — Mo/Hr: 7 / 13; OADB: 89

	Space Sens. + Lat. Btu/h	Plenum Sens. + Lat Btu/h	Net Total Btu/h	Percent Of Total (%)	Space Sensible Btu/h	Percent Of Total (%)
Envelope Loads						
Skylite Solar	343,259	0	343,259	23.74	359,043	46.43
Skylite Cond	0	18,195	18,195	1.26	0	0.00
Roof Cond	0	29,756	29,756	2.06	0	0.00
Glass Solar	154,093	0	154,093	10.66	158,600	20.51
Glass Cond	61,406	0	61,406	4.25	56,217	7.27
Wall Cond	18,773	3,977	22,750	1.57	17,838	2.31
Partition	0		0	0.00	0	0.00
Exposed Floor	0		0	0.00	0	0.00
Infiltration	0		0	0.00	0	0.00
Sub Total ==>	577,531	51,928	629,458	43.54	591,697	76.52
Internal Loads						
Lights	27,151	108,602	135,753	9.39	27,151	3.51
People	212,135		212,135	14.67	129,933	16.80
Misc	0	0	0	0.00	0	0.00
Sub Total ==>	239,286	108,602	347,888	24.06	157,083	20.31
Ceiling Load	26,012	-26,012	0	0.00	24,499	3.17
Ventilation Load	0	0	449,562	31.10	0	0.00
Ov/Undr Sizing	0		0	0.00	0	0.00
Exhaust Heat		-27,454	-27,454	-1.90		
Sup. Fan Heat			46,195	3.20		
Ret. Fan Heat		0	0	0.00		
Duct Heat Pkup		0	0	0.00		
Reheat at Design			0	0.00		
Grand Total ==>	842,829	107,063	1,445,650	100.00	773,279	100.00

HEATING COIL PEAK

Mo/Hr: 13 / 1; OADB: 17

	Space Peak Space Sens Btu/h	Coil Peak Tot Sens Btu/h	Percent Of Total (%)
Envelope Loads			
Skylite Solar	0	0	0.00
Skylite Cond	0	-68,302	8.56
Roof Cond	0	-54,617	6.84
Glass Solar	0	0	0.00
Glass Cond	-211,204	-211,204	26.47
Wall Cond	-33,365	-40,356	5.06
Partition	0	0	0.00
Exposed Floor	0	0	0.00
Infiltration	0	0	0.00
Sub Total ==>	-244,569	-374,480	46.93
Internal Loads			
Lights	0	0	0.00
People	0	0	0.00
Misc	0	0	0.00
Sub Total ==>	0	0	0.00
Ceiling Load	-50,408	0	0.00
Ventilation Load	0	-452,256	56.68
Ov/Undr Sizing	0	0	0.00
Exhaust Heat		53,202	-6.67
OA Preheat Diff.		0	0.00
RA Preheat Diff.		-24,417	3.06
Additional Reheat		0	0.00
System Plenum Heat		0	0.00
Grand Total ==>	-294,977	-797,951	100.00

TEMPERATURES

	Cooling	Heating
SADB	57.5	90.3
Plenum	78.1	62.0
Return	78.1	62.0
Ret/OA	80.6	31.9
Fn MtrTD	0.1	0.0
Fn BldTD	0.2	0.0
Fn Frict	0.7	0.0

AIRFLOWS

	Cooling	Heating
Vent	7,955	7,955
Infil	0	0
Supply	39,626	11,888
MinStop/Rh	11,888	11,888
Return	39,626	11,888
Exhaust	7,955	7,955
Rm Exh	0	0
Auxil	0	0

ENGINEERING CKS

	Cooling	Heating
% OA	20.1	66.9
cfm/ft²	1.49	0.45
cfm/ton	328.92	
ft²/ton	220.11	
Btu/hr·ft²	54.52	0.00
No. People	530	

COOLING COIL SELECTION

	Total Capacity ton	Total Capacity MBh	Sens Cap. MBh	Coil Airflow cfm	Enter DB °F	Enter WB °F	Enter HR gr/lb	Leave DB °F	Leave WB °F	Leave HR gr/lb
Main Clg	120.5	1,445.7	1,051.3	38,977	80.6	66.8	76.6	56.4	55.0	62.3
Aux Clg	0.0	0.0	0.0	0	0.0	0.0	0.0	0.0	0.0	0.0
Opt Vent	0.0	0.0	0.0	0	0.0	0.0	0.0	0.0	0.0	0.0
Total	120.5	1,445.7								

AREAS

	Gross Total	Glass ft²	Glass (%)
Floor	26,517		
Part	0		
ExFlr	0		
Roof	26,523	2,785	11
Wall	16,518	7,598	46

HEATING COIL SELECTION

	Capacity MBh	Coil Airflow cfm	Ent °F	Lvg °F
Main Htg	0.0	11,888	90.3	90.3
Aux Htg	0.0	0	0.0	0.0
Preheat	0.0	7,955	17.0	56.4
Humidif	0.0	0	0.0	0.0
Opt Vent	0.0	0	0.0	0.0
Total	-0.1			

MONTHLY UTILITY COSTS

By ae

Alternative: 1

Utility	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Total
					------- Monthly Utility Costs -------								
Electric													
On-Pk Cons. ($)	2,959	2,673	3,253	3,697	4,986	5,462	6,009	5,592	4,842	3,720	3,337	2,959	49,489
Monthly Total ($):	2,959	2,673	3,253	3,697	4,986	5,462	6,009	5,592	4,842	3,720	3,337	2,959	49,489

Zone Checksums

By ae

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COOLING COIL PEAK / CLG SPACE PEAK

	Cooling Coil Peak				CLG Space Peak	
	Peaked at Time: Mo/Hr: 7 / 14				Mo/Hr: 6 / 13	
	Outside Air: OADB/WB/HR: 91 / 77 / 121				OADB: 88	
	Space Sens. + Lat. Btu/h	**Plenum Sens. + Lat** Btu/h	**Net Total** Btu/h	**Percent Of Total** (%)	**Space Sensible** Btu/h	**Percent Of Total** (%)
Envelope Loads						
Skylite Solar	371,914	0	371,914	25.07	395,801	49.35
Skylite Cond	0	19,986	19,986	1.35	0	0.00
Roof Cond	0	30,680	30,680	2.07	0	0.00
Glass Solar	154,093	0	154,093	10.39	159,739	19.92
Glass Cond	61,406	0	61,406	4.14	50,274	6.27
Wall Cond	18,773	4,005	22,778	1.54	16,820	2.10
Partition	0		0	0.00	0	0.00
Exposed Floor	0		0	0.00	0	0.00
Infiltration	0		0	0.00	0	0.00
Sub Total ==>	606,186	54,671	660,857	44.55	622,634	77.63
Internal Loads						
Lights	27,151	108,602	135,753	9.15	27,151	3.39
People	212,135		212,135	14.30	129,933	16.20
Misc	0	0	0	0.00	0	0.00
Sub Total ==>	239,286	108,602	347,888	23.45	157,083	19.59
Ceiling Load	24,498	-24,498	0	0.00	22,322	2.78
Ventilation Load	0	0	449,789	30.32	0	0.00
Ov/Undr Sizing	0		0	0.00	0	0.00
Exhaust Heat		-25,856	-25,856	-1.74		
Sup. Fan Heat			50,603	3.41		
Ret. Fan Heat		0	0	0.00		
Duct Heat Pkup		0	0	0.00		
Reheat at Design			0	0.00		
Grand Total ==>	869,970	112,918	1,483,280	100.00	802,039	100.00

HEATING COIL PEAK

Mo/Hr: 13 / 1
OADB: 17

	Space Peak Space Sens Btu/h	**Coil Peak Tot Sens** Btu/h	**Percent Of Total** (%)
Envelope Loads			
Skylite Solar	0	0	0.00
Skylite Cond	0	-74,050	9.17
Roof Cond	0	-55,938	6.93
Glass Solar	0	0	0.00
Glass Cond	-211,204	-211,204	26.17
Wall Cond	-33,365	-40,360	5.00
Partition	0	0	0.00
Exposed Floor	0	0	0.00
Infiltration	0	0	0.00
Sub Total ==>	-244,569	-381,552	47.27
Internal Loads			
Lights	0	0	0.00
People	0	0	0.00
Misc	0	0	0.00
Sub Total ==>	0	0	0.00
Ceiling Load	-50,174	0	0.00
Ventilation Load	0	-452,256	56.03
Ov/Undr Sizing	0	0	0.00
Exhaust Heat		52,955	-6.56
OA Preheat Diff.		0	0.00
RA Preheat Diff.		-26,324	3.26
Additional Reheat		0	0.00
System Plenum Heat		0	0.00
Grand Total ==>	-294,743	-807,177	100.00

TEMPERATURES

	Cooling	Heating
SADB	58.5	88.3
Plenum	77.9	62.0
Return	77.9	62.0
Ret/OA	80.3	34.6
Fn MtrTD	0.1	0.0
Fn BldTD	0.2	0.0
Fn Frict	0.7	0.0

AIRFLOWS

	Cooling	Heating
Vent	7,955	7,955
Infil	0	0
Supply	43,469	13,041
MinStop/Rh	13,041	13,041
Return	43,469	13,041
Exhaust	7,955	7,955
Rm Exh	0	0
Auxil	0	0

ENGINEERING CKS

	Cooling	Heating
% OA	18.3	61.0
cfm/ft²	1.64	0.49
cfm/ton	351.68	
ft²/ton	214.53	
Btu/hr·ft²	55.94	0.00
No. People	530	

COOLING COIL SELECTION

	Total Capacity ton	MBh	**Sens Cap.** MBh	**Coil Airflow** cfm	**Enter DB/WB/HR** °F	°F	gr/lb	**Leave DB/WB/HR** °F	°F	gr/lb
Main Clg	123.6	1,483.3	1,088.7	42,696	80.3	66.5	75.5	57.4	55.4	62.5
Aux Clg	0.0	0.0	0.0	0	0.0	0.0	0.0	0.0	0.0	0.0
Opt Vent	0.0	0.0	0.0	0	0.0	0.0	0.0	0.0	0.0	0.0
Total	123.6	1,483.3								

AREAS

	Gross Total	**Glass** ft²	**(%)**
Floor	26,517		
Part	0		
ExFlr	0		
Roof	26,526	3,017	11
Wall	16,518	7,598	46

HEATING COIL SELECTION

	Capacity MBh	**Coil Airflow** cfm	**Ent** °F	**Lvg** °F
Main Htg	0.0	13,041	88.3	88.3
Aux Htg	0.0	0	0.0	0.0
Preheat	0.0	7,955	17.0	57.4
Humidif	0.0	0	0.0	0.0
Opt Vent	0.0	0	0.0	0.0
Total	-0.1			

MONTHLY UTILITY COSTS

By ae

Alternative: 1

Utility	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Total
					------- Monthly Utility Costs -------								
Electric													
On-Pk Cons. ($)	2,959	2,673	3,283	3,758	5,009	5,472	6,024	5,601	4,853	3,796	3,343	2,959	49,731
Monthly Total ($):	2,959	2,673	3,283	3,758	5,009	5,472	6,024	5,601	4,853	3,796	3,343	2,959	49,731

Zone Checksums

By ae

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COOLING COIL PEAK / CLG SPACE PEAK

Peaked at Time: Mo/Hr: 7 / 14 — CLG Space Peak Mo/Hr: 6 / 13

Outside Air: OADB/WB/HR: 91 / 77 / 121 — CLG Space Peak OADB: 88

	Space Sens. + Lat. Btu/h	Plenum Sens. + Lat Btu/h	Net Total Btu/h	Percent Of Total (%)	Space Sensible Btu/h	Percent Of Total (%)
Envelope Loads						
Skylite Solar	400,483	0	400,483	26.40	426,204	51.23
Skylite Cond	0	21,621	21,621	1.43	0	0.00
Roof Cond	0	31,457	31,457	2.07	0	0.00
Glass Solar	154,093	0	154,093	10.16	159,739	19.20
Glass Cond	61,406	0	61,406	4.05	50,274	6.04
Wall Cond	18,773	4,015	22,787	1.50	16,820	2.02
Partition	0		0	0.00	0	0.00
Exposed Floor	0		0	0.00	0	0.00
Infiltration	0		0	0.00	0	0.00
Sub Total ==>	634,755	57,093	691,848	45.60	653,037	78.50
Internal Loads						
Lights	27,151	108,602	135,753	8.95	27,151	3.26
People	212,135		212,135	13.98	129,933	15.62
Misc	0	0	0	0.00	0	0.00
Sub Total ==>	239,286	108,602	347,888	22.93	157,083	18.88
Ceiling Load	23,981	-23,981	0	0.00	21,777	2.62
Ventilation Load	0	0	449,835	29.65	0	0.00
Ov/Undr Sizing	0		0	0.00	0	0.00
Exhaust Heat		-25,310	-25,310	-1.67		
Sup. Fan Heat			52,791	3.48		
Ret. Fan Heat		0	0	0.00		
Duct Heat Pkup		0	0	0.00		
Reheat at Design			0	0.00		
Grand Total ==>	898,021	116,405	1,517,053	100.00	831,897	100.00

HEATING COIL PEAK

Mo/Hr: 13 / 1

OADB: 17

	Space Peak Space Sens Btu/h	Coil Peak Tot Sens Btu/h	Percent Of Total (%)
Envelope Loads			
Skylite Solar	0	0	0.00
Skylite Cond	0	-79,536	9.77
Roof Cond	0	-57,067	7.01
Glass Solar	0	0	0.00
Glass Cond	-211,204	-211,204	25.94
Wall Cond	-33,365	-40,343	4.95
Partition	0	0	0.00
Exposed Floor	0	0	0.00
Infiltration	0	0	0.00
Sub Total ==>	-244,569	-388,150	47.67
Internal Loads			
Lights	0	0	0.00
People	0	0	0.00
Misc	0	0	0.00
Sub Total ==>	0	0	0.00
Ceiling Load	-51,136	0	0.00
Ventilation Load	0	-452,256	55.54
Ov/Undr Sizing	0	0	0.00
Exhaust Heat		53,970	-6.63
OA Preheat Diff.		0	0.00
RA Preheat Diff.		-27,863	3.42
Additional Reheat		0	0.00
System Plenum Heat		0	0.00
Grand Total ==>	-295,705	-814,298	100.00

TEMPERATURES

	Cooling	Heating
SADB	58.6	87.5
Plenum	77.9	61.9
Return	77.9	61.9
Ret/OA	80.1	35.7
Fn MtrTD	0.1	0.0
Fn BldTD	0.2	0.0
Fn Frict	0.7	0.0

AIRFLOWS

	Cooling	Heating
Vent	7,955	7,955
Infil	0	0
Supply	45,420	13,626
MinStop/Rh	13,626	13,626
Return	45,420	13,626
Exhaust	7,955	7,955
Rm Exh	0	0
Auxil	0	0

ENGINEERING CKS

	Cooling	Heating
% OA	17.5	58.4
cfm/ft²	1.71	0.51
cfm/ton	359.28	
ft²/ton	209.75	
Btu/hr·ft²	57.21	0.00
No. People	530	

COOLING COIL SELECTION

	Total Capacity ton	Total Capacity MBh	Sens Cap. MBh	Coil Airflow cfm	Enter DB °F	Enter WB °F	Enter HR gr/lb	Leave DB °F	Leave WB °F	Leave HR gr/lb
Main Clg	126.4	1,517.1	1,122.5	44,542	80.1	66.4	75.1	57.5	55.5	62.6
Aux Clg	0.0	0.0	0.0	0	0.0	0.0	0.0	0.0	0.0	0.0
Opt Vent	0.0	0.0	0.0	0	0.0	0.0	0.0	0.0	0.0	0.0
Total	126.4	1,517.1								

AREAS

	Gross Total	Glass ft²	Glass (%)
Floor	26,517		
Part	0		
ExFlr	0		
Roof	26,523	3,249	12
Wall	16,518	7,598	46

HEATING COIL SELECTION

	Capacity MBh	Coil Airflow cfm	Ent °F	Lvg °F
Main Htg	-0.1	13,626	87.5	87.5
Aux Htg	0.0	0	0.0	0.0
Preheat	0.0	7,955	17.0	57.5
Humidif	0.0	0	0.0	0.0
Opt Vent	0.0	0	0.0	0.0
Total	-0.1			

MONTHLY UTILITY COSTS

By ae

Alternative: 1

Utility	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Total
					------- Monthly Utility Costs -------								
Electric													
On-Pk Cons. ($)	2,959	2,673	3,330	3,818	5,040	5,496	6,054	5,625	4,875	3,863	3,353	2,959	50,044
Monthly Total ($):	2,959	2,673	3,330	3,818	5,040	5,496	6,054	5,625	4,875	3,863	3,353	2,959	50,044

Appendix
B

60% - 30% Structural Redesign

60% - 30% Green Roof Area's

The designed green roof covers 66% of the roof while mechanical pads, skylights, and exhaust fans make up the rest of the roof. The figures below show the North Wing of the building and only half of the designed green roof. The mirror line represents the structural framing mirror line only and not the green roof mirror line. The green roof on the south wing remains the same throughout the entire analysis and is not reduced in size. The figures are titled according to the Area of the Green Roof relative to the Total Area of the Roof.

For example, the 60% Green Roof figure illustrates a roof that is 60% Green and 40% concrete. It does NOT mean 60% of the original green roof. The 30% Green Roof figure shows no green roof; however, the South Wing green roof remains the same as design so the total Green roof area is half of the original design.

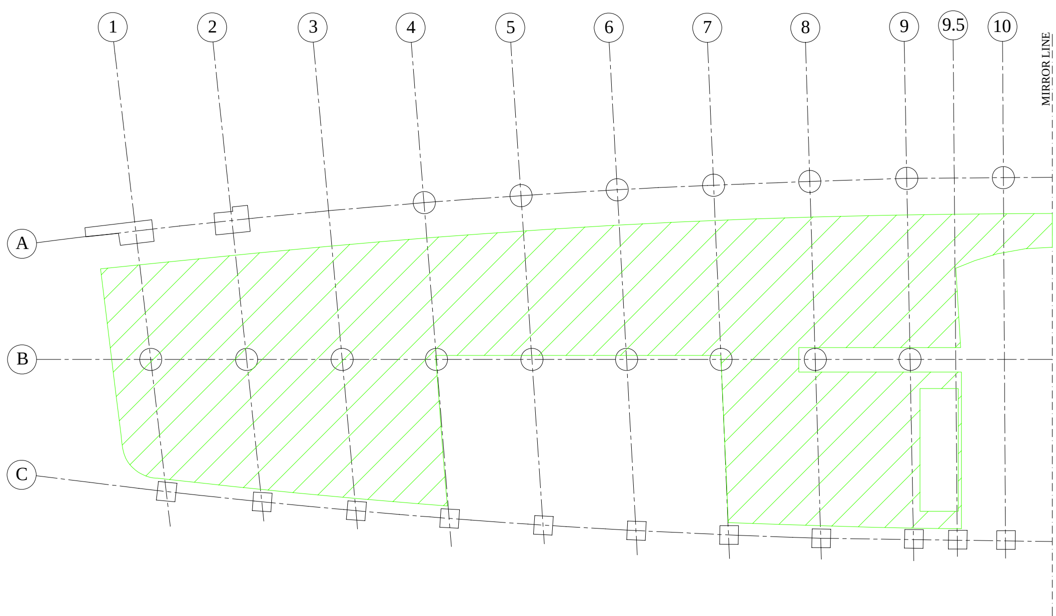

Figure B.1 – 60% Green Roof

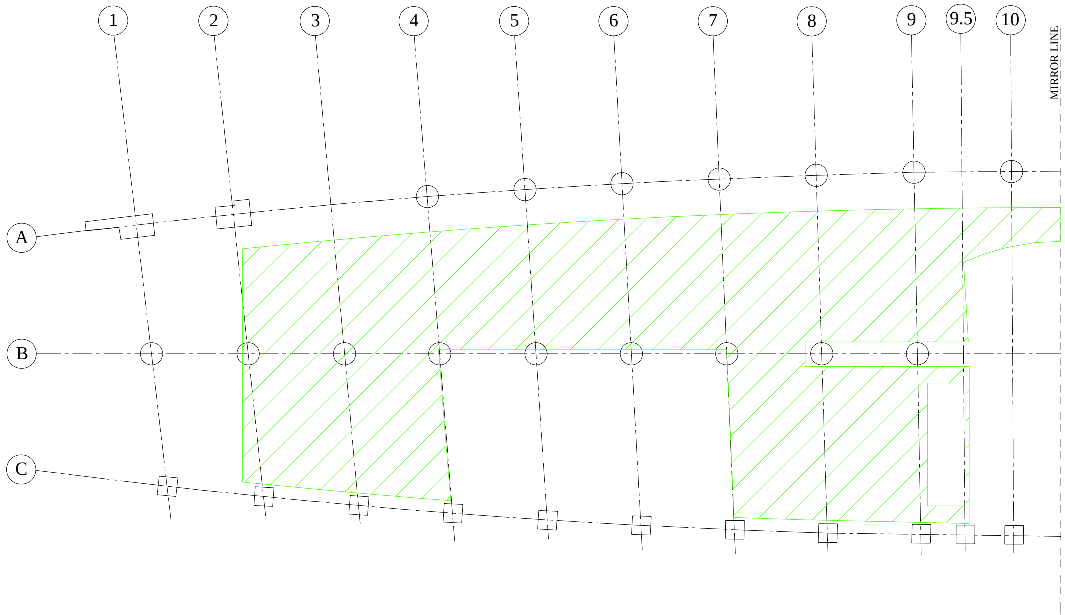

Figure B.2 – 55% Green Roof

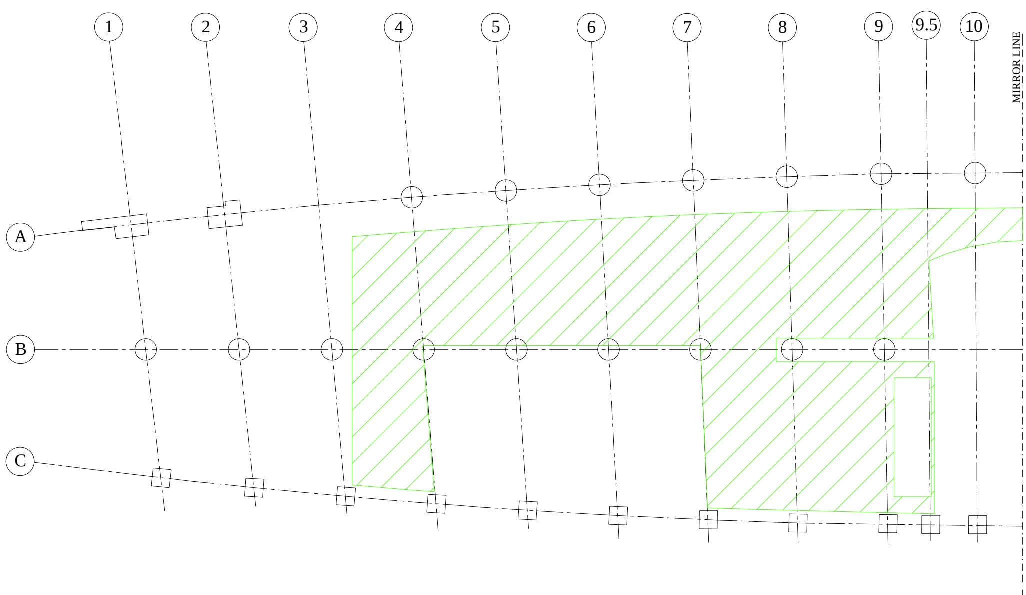

Figure B.3 – 50% Green Roof

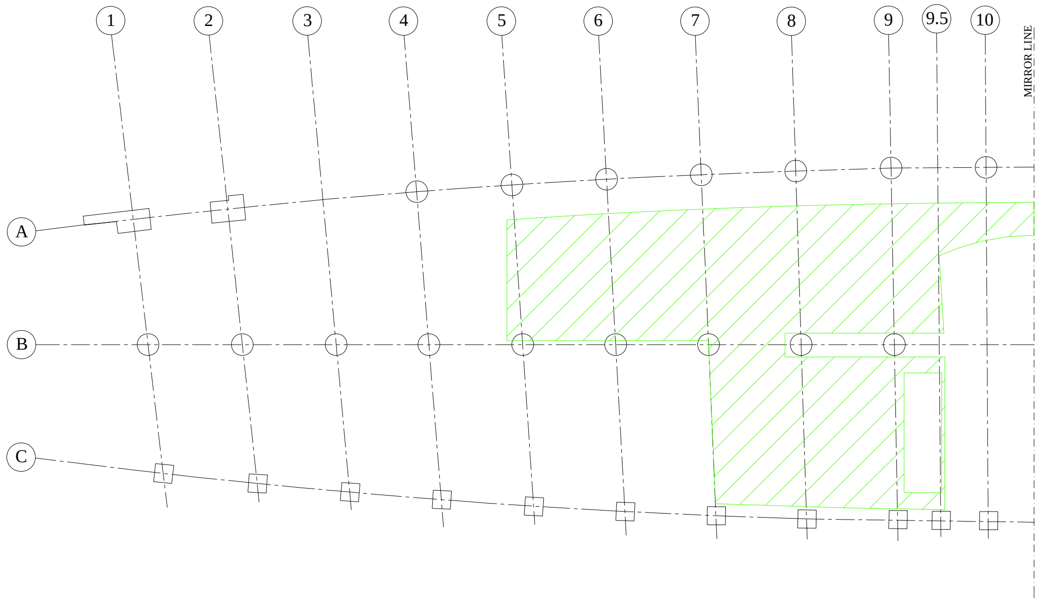

Figure B.4 – 45% Green Roof

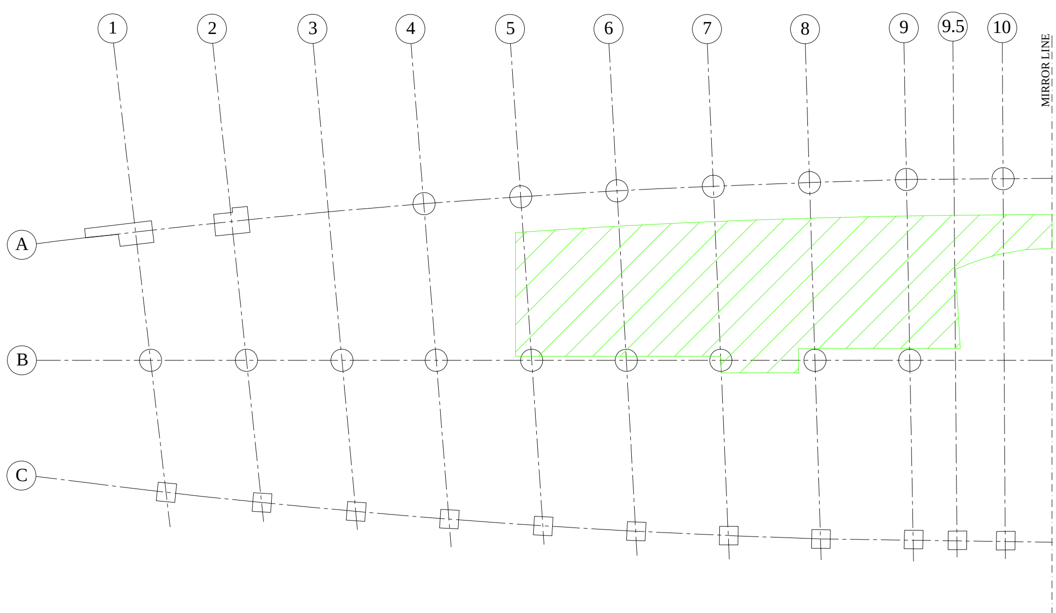

Figure B.5 – 40% Green Roof

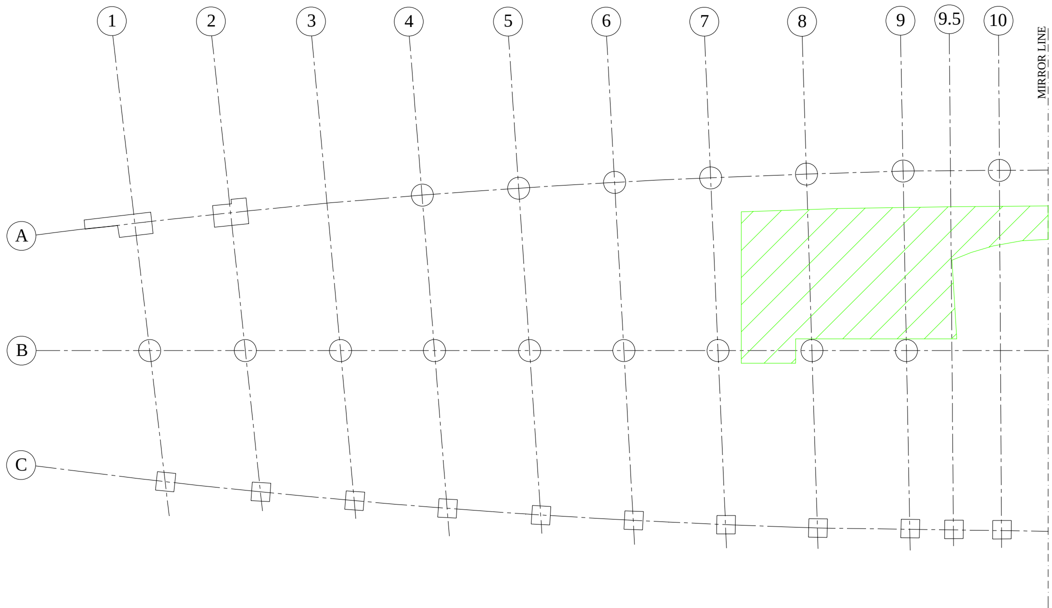

Figure B.6 – 35% Green Roof

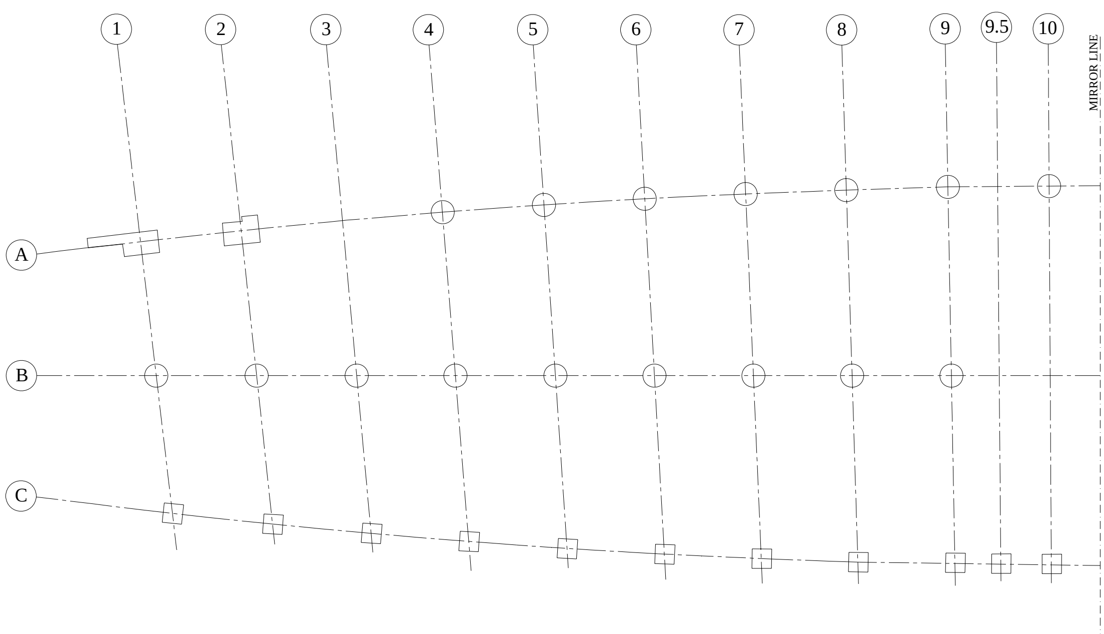

Figure B.7 – 30% Green Roof

Appendix C

Example Calculations

Determining Circular Column Load w/o G.R.

Dead Load Design : 3 kPa
Green Roof Load : 45 lb/sf = 2.15 kPa
Dead Load w/o GR: 0.85

Beam Load:
(1100 mm x 700 mm) 10 m = 7.7 m^3 x 2350
= 18095 kg

Slab Load:
(60 m^2)(200 mm) = 12 m^3 x 2350 kg/m^3
= 28200 kg

Beam/Slab Total Weight: 46295 kg = <u>102,063 lbs</u>

Tributary Area : 60 m^2 = <u>646 ft^2</u>
Dead Load: 0.85 kPa = 17.75 lb/ft^2
Live Load: 1.44 kPa = 30.08 lb/ft^2
Snow Load: 0.96 kPa = 20.05 lb/ft^2

Dead Load = 11,466.5 lbs + 102,063 lbs
Live Load = 19,431.7 lbs
Snow Load = 12,952.3 lbs

Total Load = 1.6 Live + 1.2 dead + 0.5 snow
1.6(19,431.7) + 1.2(113,529.5) + 0.5(12,952.3)
= 173802.27 lb = **173 kip**

ENERCALC - Structural Engineering Library

Circular Column Design

Tools & Settings | Help | Design | Print | Exit Quick Calc

General | Loads | Spiral Ties | ACI Factors

Description

Column Data....

Diameter	14.000	in
Total Height	19.000	ft
Unbraced Length	19.000	ft
f'c	3,000.0	psi
Fy	60,000.0	psi
Seismic Zone	4	
Include LL w/ ST Loads	☐	

Reinforcing....

Number of Bars	8	
Bar Size	8	
Total Rebar Area	6.320 in2	: 4.106 %
Bar Cover	2.000	in

Stirrups / Slenderness...

Eff. Length Factor	1.000
Column is Unbraced	☐
Delta:S	1.000

Results | Sketch | Diagrams | Printing

Column is OK

	ACI Eq. C-1	ACI Eq. C-2	ACI Eq. C-3	
Pu : Max Factored	**167.29**	**176.96**	**120.21**	k
Pn * Phi @ Dsgn Ecc.	**296.25**	**264.23**	**351.69**	k
M-critical	14.22	15.04	10.22	k-ft
Combined Eccentricity	1.0200	1.0200	1.0200	in
Magnification Factor	2.59	3.13	1.82	
Design Eccentricity	2.6459	3.1878	1.8553	in
Magnified Moment	36.89	47.01	18.59	k-ft
Po * 0.85	642.28	642.28	642.28	k
P : Balanced	157.84	157.84	157.84	k
Ecc : Balanced	9.5042	9.5042	9.5042	in

Slenderness.....

Actual k Lu / r	65.143	Beta	0.850
Elastic Modulus	3,122.019 ksi		

	ACI Eq. C-1	ACI Eq. C-2	ACI Eq. C-3	
Neutral Axis Distance	10.4070	9.7170	11.8770	in
Phi	0.7000	0.7000	0.7000	
Max Limit kl/r	34.0000	34.0000	34.0000	
Beta = M:sustained/M:max	0.8141	0.8979	0.8498	
Cm	1.0000	1.0000	1.0000	
EI / 1000	1,911.90	1,827.48	1,875.09	
Pc : pi^2 E I / (k Lu)^2	362.99	346.96	356.00	
alpha: MaxPu / (.75 Pc)	0.6145	0.6800	0.4502	
Delta : Magnification Factor	2.5940	3.1253	1.8189	
Ecc: Ecc Loads + Moments	1.0200	1.0200	1.0200	in
Design Ecc = Ecc * Delta	**2.6459**	**3.1878**	**1.8553**	in

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ENERCALC - Structural Engineering Library

Circular Column Design

Tools & Settings | Help | Design | Print | Exit Quick Calc

General | Loads | Spiral Ties | ACI Factors

Description

Column Data....

Diameter	14.000	in
Total Height	19.000	ft
Unbraced Length	19.000	ft
f'c	3,000.0	psi
Fy	60,000.0	psi
Seismic Zone	4	
Include LL w/ ST Loads	☐	

Reinforcing....

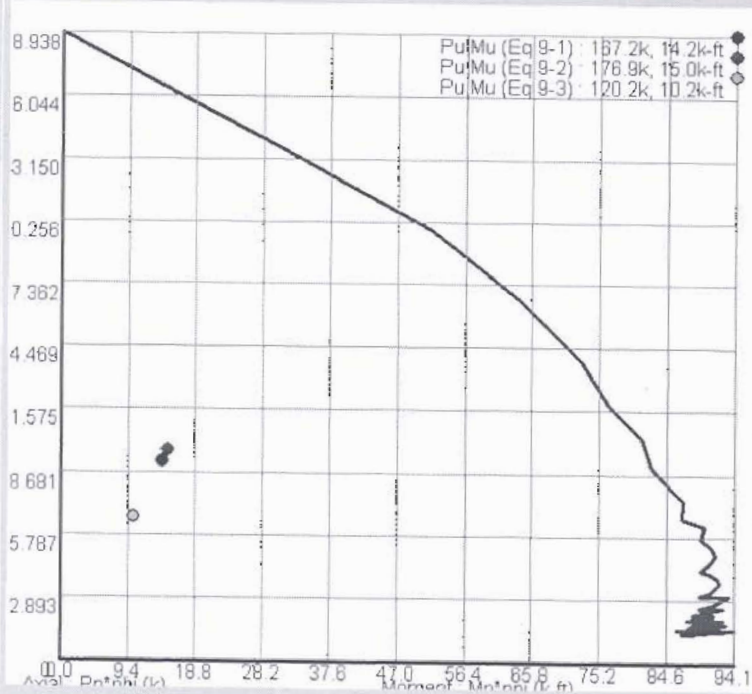
Number of Bars	8	
Bar Size	8	
Total Rebar Area	6.320 in2	: 4.106 %
Bar Cover	2.000	in

Stirrups / Slenderness...

Eff. Length Factor	1.000
Column is Unbraced	☐
Delta S	1.000

Results | Sketch | Diagrams | Printing

Graphic Diagram | Data Table | Print Diagram



RS Means Sample Calculation - 14" Diam. Column's

Formwork: \$10.43/L.F × 19' = \$198.17

Rebar (#8): \$1405/ton × (19' × 2.67 lb/ft × 8 bars × 1 ton/2000 lb)

= \$285.10

Concrete Mix (3000 psi): \$87/C.Y. × $\left(\frac{\pi}{4}\left(\frac{14}{12}\right)^2 \times 19' \times 0.037037 \frac{C.Y.}{cf}\right)$

= \$65.45

In Place: \$564.75/C.Y. × (0.7523 CY) = \$424.84

Sub total: \$975

Location Factor: 0.897

Total Cost = \$875 per column