Mechanical Analysis

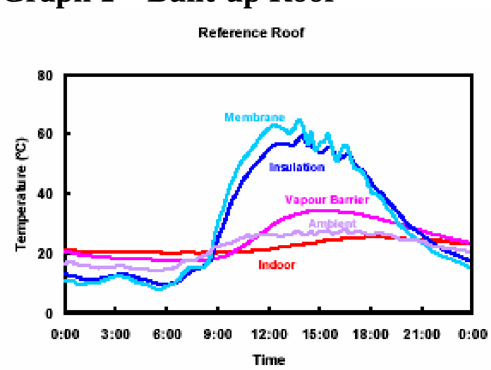
4.1 - Energy Savings

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)

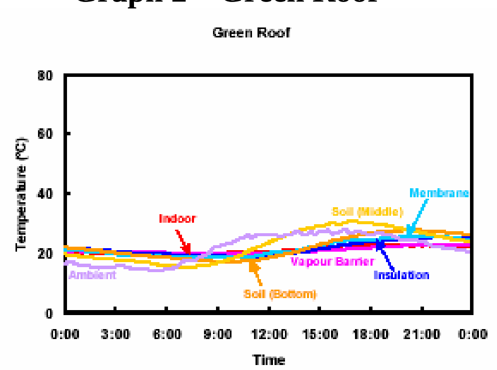
Since the CSUF has not been built and there is no existing load data, energy savings due to the green roof had to be estimated. To estimate these energy savings, Trane's TRACE700 program was used. This program simulated the green roof as an extra layer of insulation. Hydrotech provided estimates of their 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.