ROOF SYSTEM ANALYSIS
Built-up roof vs. green roof system

Objective

The objective of the green roof analysis is to determine the impact a green roof would have on the AHIB. The main focus is to discover the structural load requirements if a green roof had been used instead of a traditional built-up roof. In addition to the structural requirements, the mechanical difference is examined to learn whether a green roof would help the efficiency of the mechanical system. The cost and scheduling comparison is made between a traditional 4-ply built-up roof and a green roof. Although other comparisons can be made, the mechanical and structural comparison is the focus of comparison between the different roof systems.

The structural area analyzed is a single bay consisting of W10x12 beams and W27x84 girders. Although the total roof area of the AHIB is approximately 25,442 square feet, a representative sample of 3,648 square feet over the theater is used for analysis. The current mechanical system in place is a 9,000 c.f.m rooftop air handling unit dedicated to only the theater. The AHU has a cooling capacity of 50 tons.

What is a Green Roof?

A green roof is an engineered roof system that allows for the propagation of roof-top vegetation. Green roof systems are widely considered to be energy savers due to their ability to remain cool even in hot summer months. Other benefits include reducing the amount of storm-water runoff. While there are many green roof manufacturers, there are only two major categories of green roof construction: intensive and extensive green roofs.

Intensive systems typically use larger plant types. These systems require a larger amount of soil, typically to a depth of at least 12 inches. Intensive systems are heavy, require more maintenance, and are more costly. Intensive green roof systems fall between the

ranges of 80-150 lb/sf. Extensive roof systems use smaller plants—typically sedums, grasses, and wildflowers. These systems are lower in weight since the plants require less soil (usually only about 4-6 inches) and fall between the ranges of 15-50 lbs/sf. Also, extensive systems do not require as much maintenance and typically are less expensive overall (www.earthpledge.org).

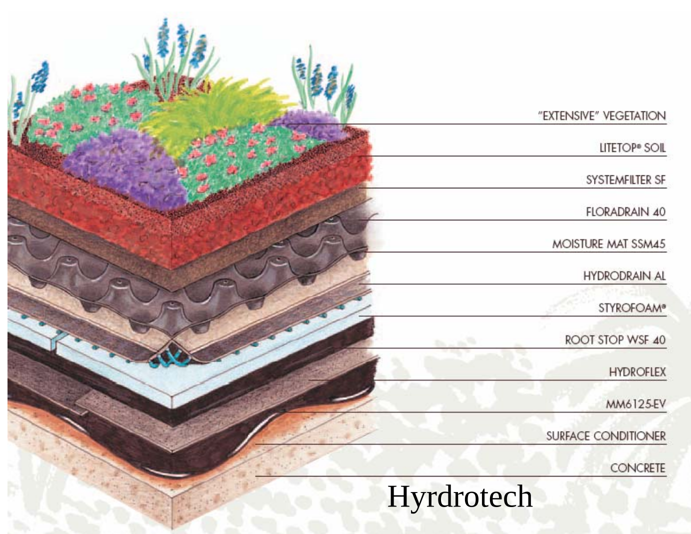
Geographic Requirements

Green roofs are not specific to any one region or area of the country. However, when designing a green roof, it is important to consider the climate in which it will be constructed and the type of plants best suited to that climate. Since some plants are more resistant to heat or cold and certain features of a particular climate, the proper plant selection is important to ensure that the green roof is capable of surviving the different seasons. According to D.C. Greenworks, a nonprofit organization that promotes sustainable design, the preferred plant types in the Maryland area are plants from the *Sedum* genus. There are several different species that are easily adaptable to green roofs. Sedums are particularly suited for use in green roof construction because they have high water-retention capability, an ability to filter pollution, and are resistant to temperature fluctuations. Also, they require minimal maintenance (www.epa.gov/heatisland).

Construction Materials

Every green roof system can be analyzed into five basic components. These components are:

1. Vegetation Layer
2. Soil Layer
3. Drainage Layer
4. Non-permeable Layer
5. Roof Construction



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The specific environment of the green roof dictates the design of the vegetation layer. A few considerations when choosing specific plants include: specific climates, expected rainfall, drought resistance, resistance to radiation, and resistance to snow.

The soil layer is designed following the selection of the plant types. A soil layer should retain water for the plants and control water drainage. Most important, the soil layer needs to allow for the growth of the plants.

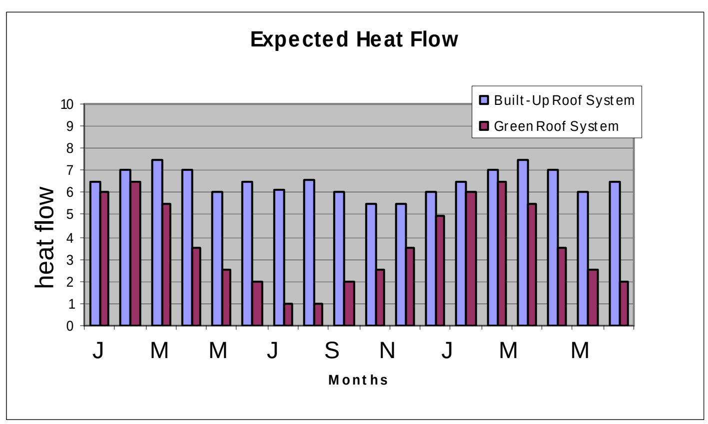
The drainage layer is important to control the flow of excess water through the green roof system. A waterproof layer is installed beneath the drainage layer to prevent moisture from damaging the roof construction. The roof construction is the structural support of the green roof system.

Structural Load Requirements

The approach taken to design the green roof involved checking the structure to understand how much additional load the existing steel roof frame could support. The goal is to avoid creating a load that will require the redesign of the structural system. First, a typical bay is selected as the area to analyze. Since the green roof's weight is unknown at this time, the objective is to determine the maximum weight (lbs/sf) for the green roof. An unknown variable "P," representing the weight of the green roof, is applied uniformly to the roof bay. A shear, moment and deflection check is performed on both the roof beams and girders whose size is already known and taken from the existing structural drawings. The calculations are described in the Appendix A. From the calculations found in the appendix it is determined that the maximum the green roof can weigh is 67 psf. After the weight of the green roof is determined, a decision is made to design an extensive or intensive green roof. Based on the structural requirements, an extensive green roof is selected. An extensive green roof will be approximately 15-50 psf. Based on the knowledge that green roofs typically weigh 6 psf/in when fully saturated, a good design for these requirements would be an extensive green roof with 6 inches of soil, weighting approximately 36 psf. Under this load condition, the extensive green roof meets structural load requirements.

Mechanical Implications

Green roofs are known to possess certain benefits regarding thermal efficiency. However, it is difficult to quantify the exact thermal efficiency due to a couple of factors. Currently, no R-value is calculated and assigned to green roof systems. This is because the R-value of a green roof changes when it is at different saturation levels. Also, because of the drainage requirements of a green roof, there are different soil depths at different parts of the roof. Case studies have been performed under specific conditions in an attempt to calculate exactly what thermal properties are specific to a green roof. From these case studies it is shown that, from a thermal standpoint, a green roof is most beneficial in the summer months. Additional reports conclude that the reduction of heat entering the building in the summer is greater than the reduction of heat exiting the building in the winter. These quantities may not be universal to all green roofs since each system is in a different environment, undergoes different saturation levels throughout its usage and uses different growing mediums. One such study conducted in Canada resulted in the observation that, during the summer months, the green roof reduced the roof surface temperature by 35° F and reduced the heat flow through the roof by 70% to 90%. The same roof system reduced the heat flow through the roof by 70% to 90% in the summer months. Another case study conducted at the University of Central Florida found a reduction heat flow reduction of 20% in the summer months. The green roof system used at in the University of Central Florida's case study previously mentioned is very similar in physical dimension to a portion of the green roof system proposed for the AHIB. Therefore similar thermal properties are expected and will be used as the baseline for comparison to the AHIB project, specifically the roof area above the theater. The adjacent table is an



example of the goal for the heat flow through the roof of the AHIB assuming similar results apply. The objective is to reduce the high fluctuations of heat through the roof resulting in a mechanical system that runs with less energy. Only cooling will be examined because the greatest benefits are going to be in the summer. An example of the heat flow equations is listed below:

$q_x = (T_o - T_i) * A / R$

q_x = Heat flow through the roof system, BTU / Hr

T_o = Temperature outside, °F

T_i = Temperature inside, °F

A = Area, 3,648 s.f. of roof surface area over the theater

R = R-value, thermal resistance coefficient, hr * ft^2 * °F / BTU

The inside and outside design temperatures are found in *Construction: Principles, Materials, and Methods*.

<u>Built-up roof:</u>

The r-value for the built-up roof is calculated to be 15.89

Cooling: q_x = (91 - 68) * 3,648 / 15.89 = 5,280 BTU / Hr

<u>Green roof:</u>

Based on the case study the heat flow reduction is assumed to be 20%. This is a conservative estimate since a different study resulted in a reduction of 70%-90%. The 20% reduction is also justified because the green roof system in the case study as well as the one designed for the AHIB are very similar in depth and surface area. To further justify the calculations the r-value must be calculated to determine if it falls in an appropriate range. First, the new heat flow will be calculated and the resulting r-value will be checked against the result of the case study.

Cooling: q_x = 5,280 BTU / Hr * 20% reduction = 4,224 BTU / Hr

Resulting r-value

Cooling: r-value = (91 - 68) * 3,648 / 4,224 BTU / Hr = 19.86 hr ft^2°F / BTU

This results in a conservative r-value of 19.86 which is consistent with the expected data range of R-15 to R-60.

The conclusion is specific to the area analyzed, which in this case is limited to the theater space. The 4,224 BTU/HR heat flow reduction can be converted to cooling load reduction on the dedicated air handling unit. The AHU's cooling load is 50 tons. By reducing the heat flow 4,224 BTU/HR, the load on the AHU decreases by .352 tons. This is an insignificant amount compared to the total tonnage of the AHU and will not result in any upfront financial cost savings because the AHU can not be reduced by only .352 tons.

Material Cost Savings & Schedule Considerations

The cost comparison for the roofing system is between a 4-ply built-up roof system and a green roof system. Based on RS Means2005 data, it is determined that a 4-ply built-up roof installed will cost approximately $1.98 per square foot. In the United States green roofs systems can cost in the range of $9-$24 per square foot of roof installed. This is significantly greater than a 4-ply built up roof. A cost of $15 per square foot is used for the green roof based on case studies in the District of Columbia area. The comparison between the two systems is based on the installation of 3,648 sq. ft. of roof. The following table summarizes the furnished and installed costs for both roof systems.

<u>Material and Installation Summary Table</u>:

3,648 square ft of roof area

Built-Up Roof @ $1.98 = $ 7,223

Green Roof @ $14.43 = $ 52,640

In addition the following table summarizes the productivity rates for installation of both systems:

<u>Productivity Rates:</u>

Built-Up Roof @ 2,000 sq. ft installed per day = 2 total installation days

Green Roof @ 1,800 sq ft installed per day = 3 total installation days

Based on the previous calculations, the built-up roof system is cheaper and can be installed 1 day faster. From material and installation costs, $45,417 will be saved if the built-up roof system is chosen.

Conclusion

The recommendation for the owner is to install the built-up roof system. Although from the analysis a green roof adds no additional requirements for the structural system, the initial material costs outweigh some of the added benefits. The green roof does offer some mechanical savings by allowing the mechanical system to use less energy in the summer time, which would help reduce costs in the long run, but the initial cost savings is minimal. The analysis above focuses on the initial cost of material and installation of two different roofing systems, a green roof and a 4-ply built-up roof system. The analysis concludes that a built-up roof system is cheaper because of its lower material cost as well as lower labor cost due to faster installation.