ANALYSIS 1:
GREEN ROOF DESIGN

Problem Statement:

With the majority of the buildings flat roof designed as a cool roof, the boiler/chiller building's roof was designed to have a green roof. Located on the northwest corner of the building and separated from the rest of the building, design may be questioned as to why the green roof was used. Being located behind the building, only those who park in the back parking lot as well as only a few offices on the second floor will be able to see the green roof. In addition, with the boiler/chiller building not needing to be cooled or heated as much as the main building, the thermal benefits of a green roof have been lost.

View of Geisinger Gray's Woods Ambulatory Care Campus from Gray's Woods Boulevard. Personal Photo.

Proposed Solution:

The goal of this analysis is to investigate the effects of relocating the current green roof on the boiler/chiller building to the sloped front roof of the building. Building envelope calculations along with solar radiation calculations will be used to evaluate the effects on short term and long term effects on the mechanical equipment. Additionally,

building sections and renderings will provide the aesthetics of the redesign and relocation of the green roof. Various green roof systems will be researched to find the optimal system for the steep sloped roof.

Methodology:

The first step will involve researching the varying green roof systems currently used for steep sloped roofs after initially analyzing the current roofing systems. These systems will be evaluated by cost, schedule impacts, and the constructability of the system. A proposed green roof will then be selected.

With the best system selected, Architectural drawings will be produced using AutoCAD. To demonstrate the differences between the current system and the proposed system, building sections, section details, and renderings will be used.

Lastly, the thermal effects of the proposed green roof will be determined using an Microsoft Excel Spreadsheet. The mechanical equipment energy savings converted to dollar savings will show both initial and life cycle costs with the new system.

Resources and Tools:

Architect and HVAC Engineer – EwingCole

Roofing Subcontractor – R.H. Marcon, Inc.

AutoCAD

Microsoft Excel

Professor Robert Holland

Professor James Freihaut

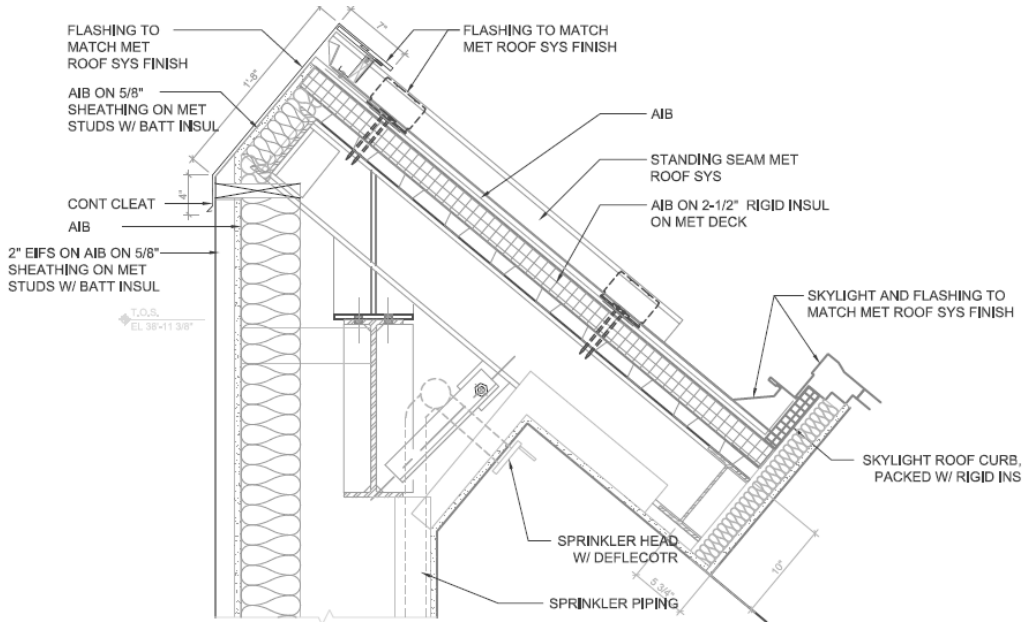
Green Roof Manufacturer – Xero Flora America, LLC

Existing Conditions:

The Gray's Woods Medical Office Building's main entrance and curtain wall system are orientated to the south to allow for the maximum amount of daylighting for the building. The roof over the curtain wall consists of a metal and skylight system that creates a dramatic façade while providing shading during the summer months.

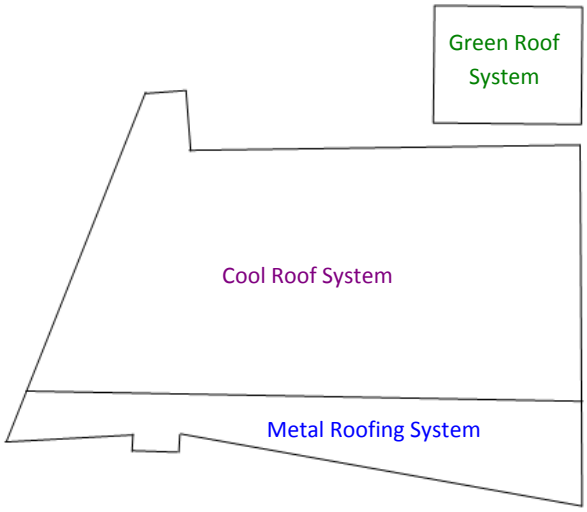
Rendering of Geisinger Gray's Woods Medical Office Building.

With the building striving for LEED Certification apon completion, the roof systems used played a key part in earning additionaly LEED points. First, the sloped metal roof is highly insulated, locally available and is specified to have a long life span.



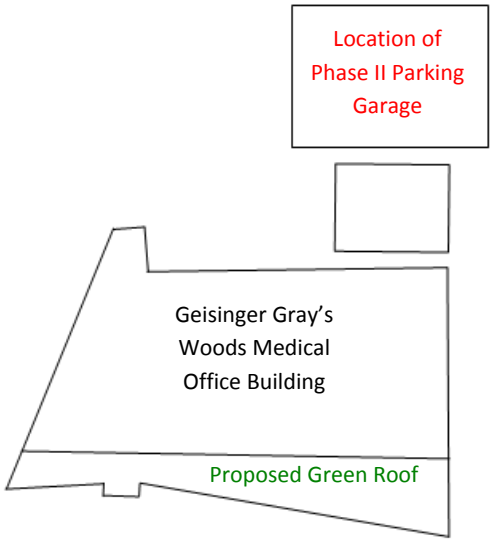
Section Detail at Roof Slope of Metal Roofing System. Additional Building Sections and Section Detail Drawings in Appendix A.

Next, the main area of the roof consists of once again a thick layer of insulation, and has a "cool roof" membrane to reduce the heat island effect. Lastly, the boiler/chiller building which is detached from the rest of the building, is designed to have a green roof system with additional insulation.



Plan of Different Roofing Systems Used.

Green roofs are known to have many benefits for the building and the surronding environment. In Gray's Woods case, the two main reasons they used a green roof on the boiler/chiller room is for stormwater management, and to increase the aesthetic value of the building. After Phase I – the medical office – Phase II of the project consists of a parking garage adjacent to the boiler/chiller building.



Plan with Future Parking Garage.

Owners and Architects felt strongly about veiwing the green roof from the green roof from the parking garage – instead of just a typical black commercial roof – due to it's design success at one of Geisinger's Danville, PA locations.

Architectural Impacts:

When proposing to relocate the green roof from behind the building to the front façade, a stronger impression is created by the building. Being located in a non-urban area, it is important to restore and preserve the portion of the natural habit destroyed by the buildings foot print.

Rendering of Geisinger Gray's Woods with the proposed Green Roof.

Geisinger's approach to creating sustainable and environmentally friendly offices is an asset to the entire community. Although it seems by placing the green roof where only future clients parking in the parking garage can see their contribution, they are not completely supporting the "Green Movement". By relocating the green roof more than just the small percentage of people parking in the "not yet" parking garage will see the green roof. Then, all those passing by on Gray's Woods Boulevard as well as the adjacent US 322 Highway will see and know what Geisinger stands for thus creating more community attention and support.

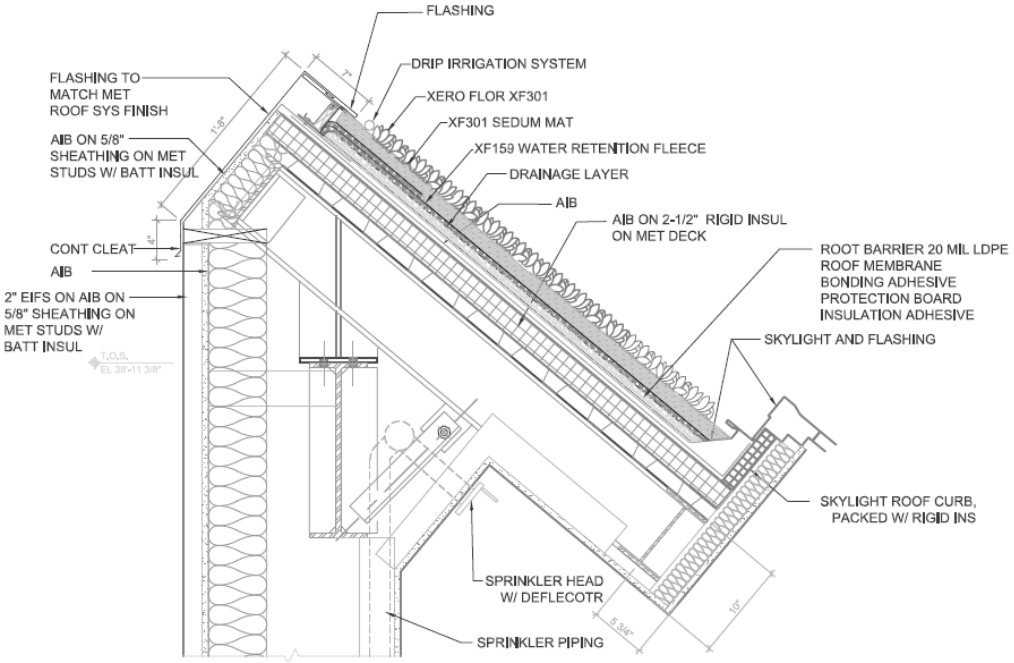
Xero Flor Green Roof System

The XF301 System is a lightweight extensive green roof system containing a special blend of Sedums and other succulents. The Xero Flor green roof mats are tolerant of the extreme conditions of rooftops. The plants used are naturally drought resistant and low profile so they require very little maintenance. The textile-based carrier design is easier assembly and less waste than injected-plastic trays and the pre-vegetated mat design can accommodate steep slopes angles such as the one on Gray's Woods.

System Profile of the Xero Flor Extensive Green Roof Mats.

While keeping the same amount of roofing insulation, the metal roofing system can simply be replaced by the Xero Flor green roof system with very little additional materials. First, a typical waterproofing roofing membrane is necessary. To keep the plants at the peak of the sloped watered and green, a drip irrigation system and additional layer of water retention fleece is required. The water necessary for the irrigation system could be obtained from a small rainwater collection. Additionally, a vertical taking strip spaced about 40" on center is necessary to anchor the mats to the steep slope.

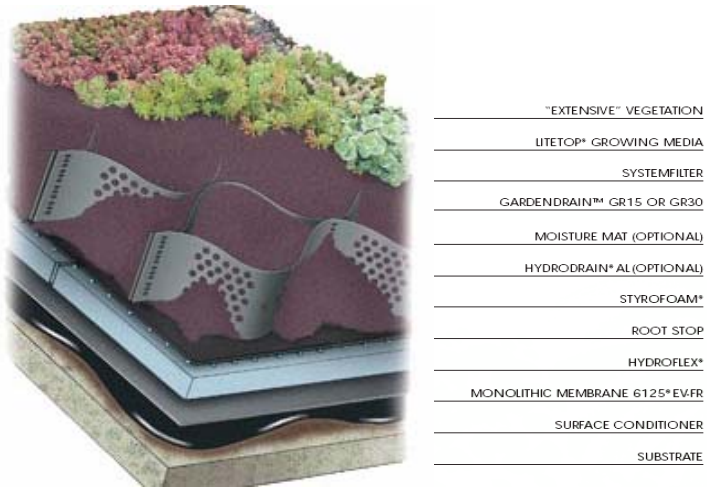
Tacking Strips and Rolled Mats Used on Previous Project.



Section Detail at Roof Slope of Xero Flor Green Roof System. Additional Building Sections and Section Detail Drawings in Appendix A.

American Hydrotech Green Roof System

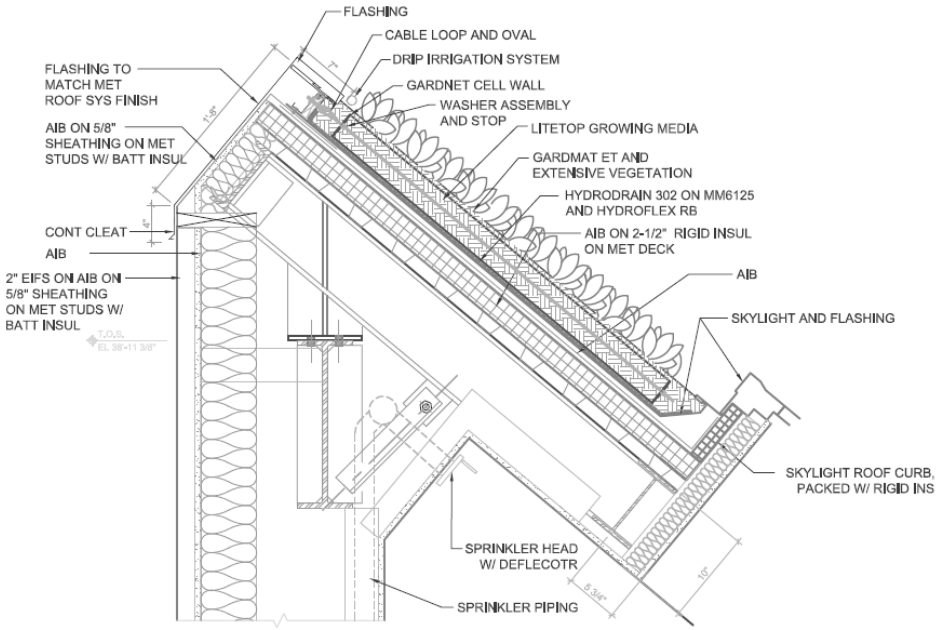
The American Hydrotech's Garden Roof Asembly is a lightweight and low profile extensive green roof system. Suited for locations that will receive little or no maintenance, the soil mixture is comprised of mineral materials mixed with organic matter. Recommended plants include sedum, herbs, and grasses.



System Profile of the American Hydrotech Extensive Green Roof System.

While keeping the same amount of roofing insulation, the metal roofing system can easily be transformed into the Garden Roof System with few additional materials. First, a typical waterproofing roofing membrane is necessary. To keep the plants at the peak of the sloped watered and green, a drip irrigation system similar to the system used for the Xero Flor System is required. To keep the system in place, the sloped application includes a soil stabilization system. The following photo shows the soil stabilization system as used on a previous sloped project.

Gardnet Soil Stabilization System



Section Detail at Roof Slope of American Hydrotech Green Roof System.
Additional Building Sections and Section Detail Drawings in Appendix A.

Mechanical Impacts:

For low rise buildings, roofing systems can have substantial impacts on the mechanical equipment loading. To calculate to environmental loading on the equipment, the building envelopes thermal resistance is typically measured as well as the roofs solar absorption. Both of these features combine to reduce the Urban Heat Island Effect.

For this analysis, only the area of the slope roof has been considered since the rest of the building envelope system will not change.

To begin, with additional mass and resistance, green roof systems can reduce thermal loading on mechanical equipment. Roof materials are given an R-value (hr*ft^2°F/Btu) which is the resistance of one square meter of the material to a one degree temperature change. Appendix C contains the thermal resistance calculations for all three roofing systems. Below is a chart demonstrating the R-values for each roofing system.

Table 1: Total R-Values of Varying Roof Systems

	Metal Roof Current Design	Xero Flor Roof	Hydrotech Roof
R-Value	21.83	23.48	23.34
Difference from Current Design		-1.65	-1.51

From these values, the heat flow rate (Btu/hr) for the roof system can be calculated using the following equation:

$$\text{Heat Flow Rate} = \frac{\text{Area of Roof x Cooling Load Temperature Difference (CLTD)}}{\text{R-value of Roof System}}$$

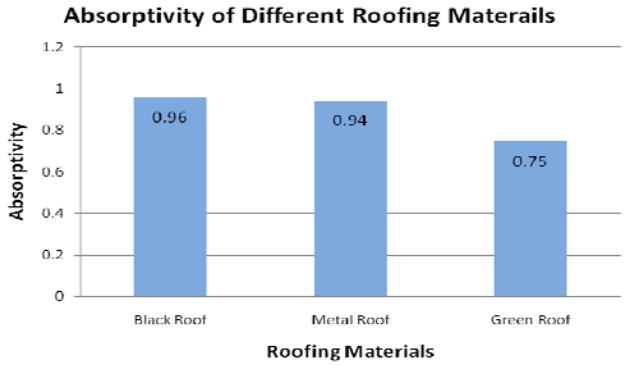
The design temperature change was found by taking the indoor design temperature (70°) and subtracting it from an extreme outdoor temperature (130°). The heat flow rate could then be multiplied by the degree days to find the about of Btu's per year (load on the mechanical equipment). This load is only a portion of the entire thermal load on the mechanical equipment since only the slope roof area was considered. Below is a table of the thermal loads on the equipment for each roofing system from the thermal resistance of the roofing systems can be found.

Table 2: Btu/Year Based on Thermal Resistance of Varying Roof Systems

	Metal Roof Current Design	Xero Flor Roof	Hydrotech Roof
Btu/Year	543,191,351	505,019,898	508,049,152
Difference from Current Design		38,171,454	35,142,200

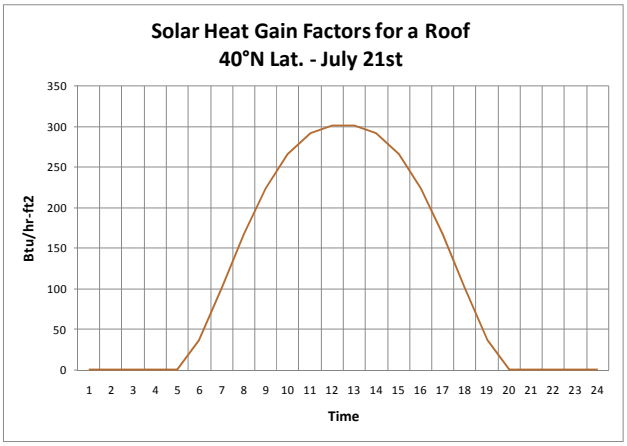
Based on the calculations, with the higher R-value systems, the amount of heat gain per year is reduced. Specifically, both the Hydrotech Green Roof System and the Xero Flor Green Roof System provided about 7% heat gain reduction for the Geisinger Gray's Woods Building.

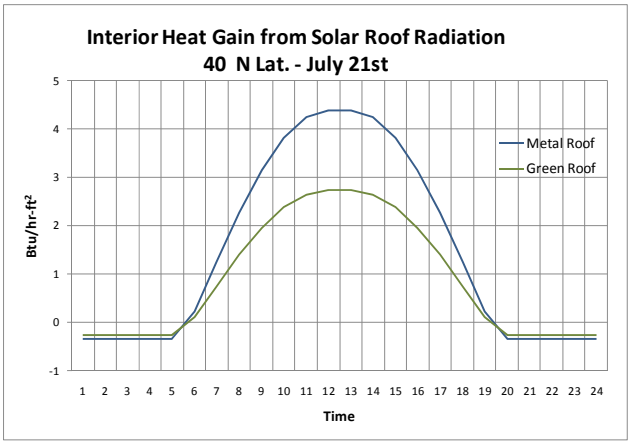
To complete the mechanical analysis, the roof systems solar absorption was considered as well. Depending on the absorptivity of the roof material, a portion of the solar heat gain is absorbed into the roof itself and is eventually radiated into the interior of the building proportionally. Below are the absorptivity values of three typical roofing materials.



Absorptivity Values of Different Roofing Materials.

After obtaining the solar heat gain factors (Btu/hr-ft^2) for 40°N Latitude for July 21st, the actual incident solar radiation on the roof was found my multiplying the solar heat gain factors by 1.15. The solar heat gain factors chart can be found in Appendix C. By multiplying the roofs absorptivity value by the actual incident solar radiation, the amount of heat gain radiated into the interior of the building can be calculated. Below are two charts demonstrating the solar heat gain and interior heat gain for the July 21st date.



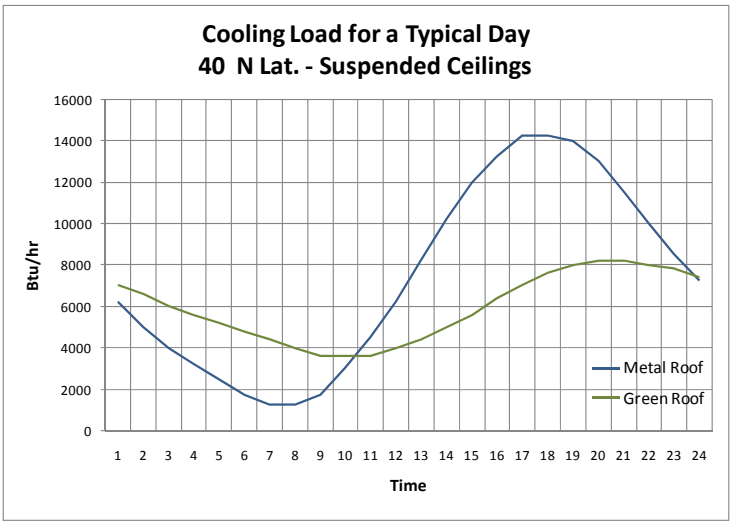


From these charts we can see that a green roof will absorb less heat then a metal roof and thus have less heat to radiate into interior spaces of the building.

To find the cooling loads on the building from the solar radiation heat gain, the following equation can be used:

$$\text{Cooling Load from Heat Gain} = \frac{\text{Area of Roof x Cooling Load Temperature Difference (CLTD)}}{\text{R-value of Roof System}}$$

A chart of the CLTD numbers for different roofing systems with a suspended ceiling at 40°N latitude can be found in Appendix C. Since a green roof has a higher R-value and a great absorptivity, the CLTD numbers for a green roof will be lower and delayed as compared to a metal roof system. The following graph demonstrates this.



When taken into consideration for an entire year, each hourly Btu for a typical day is added and multiplied by the number of sunny days for the region. This results in a final Btu/year for both systems as demonstrated in the table below. Further calculations can be found in Appendix C.

Table 3: Btu/Year Based on Solar Radiation of Varying Roof Systems

	Total Btu/Day	# of Sunny Days Per Year	Total Btu/Year
Metal Roof	177,250	215	38,108,750
Green Roof	142,000	215	30,530,000

Comparing these numbers to the Btu/year for the thermal resistance, the solar radiation load plays a small role. When combining both thermal resistance heat gain and solar

radiation heat gain for cooling loads, the following has been calculated for each system with the difference from the current design showing that the green roof systems reduce the cooling load by 7% per year.

Table 4: Btu/Year Based on Thermal Resistance & Solar Radiation of Varying Roof Systems

	Metal Roof Current Design	Xero Flor Roof	Hydrotech Roof
Btu/Year	581,300,101	535,549,898	538,579,152
Difference from Current Design		45,750,204	42,720,950

Cost Analysis:

Initial costs of the varying building constructions include the components used in each roofing system. All roofing systems include the standard components (roofing membrane, insulations, and adhesives) unless otherwise noted. Other components added include additional materials for the green roof systems.

All cool roof, metal roof, current green roof, and sloped Hydrotech green roof systems costs have been obtained from the roofing subcontractor – R.H. Marcon, Inc. The roofing subcontractor has also supplied the additional building material costs – roofing membrane, insulation, irrigation system, and plants for the green roofs. The Xero Flor green roof systems costs and shipping costs were obtained by Xero Flor America, LLC. All costs include labor and installation.

The current design of the all roofing systems costs a little over $422,000. Below is a Microsoft Excel spreadsheet of the current roofing systems costs.

Table 5: Green Roof, Cool Roof, Metal Roof (Current Design of Building)

Current Roofing Systems					
	Amount		Cost		Total
Green Roof - Boiler Room	3290	SF	25	$/SF	82,250
+ Plants for Green Roof	3290	SF	5	$/SF	16,450
Cool Roof - Flat Main Roof	24200	SF	10	$/SF	242,000
Metal System	5105	SF	16	$/SF	81,680
				PRICE	***$422,380***

When moving the green roof to the sloped area with the Hyrdotech green roof system, the priced is increased to about $466,000. In this case, the boiler/chiller building now has a cool roof system. The top of the next page shows a table of the green roof relocation using the Hydrotech green roof system.

Table 6: Cool Roofs, Hydrotech Green Roof System

Relocation of Green Roof - Hydrotech					
	Amount		Cost		Total
Cool Roof - Boiler Room	3290	SF	10	$/SF	32,900
Cool Roof - Flat Main Roof	24200	SF	10	$/SF	242,000
Green Roof - Sloped	5105	SF	32	$/SF	163,360
+ Irrigation					2,500
+ Plants for Green Roof	5105	SF	5	$/SF	25,525
				PRICE	***$466,285***

When moving the green roof to the sloped area with the Xero Flor green roof system, the priced is reduced to about $396,000. In this case, the boiler/chiller building now has a cool roof system. Below is a table of the green roof relocation while using the Xero Flor green roof system.

Table 7: Cool Roofs, Xero Flor Green Roof System

Relocation of Green Roof - XeroFlor					
	Amount		Cost		Total
Cool Roof - Boiler Room	3290	SF	10	$/SF	32,900
Cool Roof - Flat Main Roof	24200	SF	10	$/SF	242,000
Green Roof - Sloped	5105	SF	13	$/SF	66,365
+ Shipping Costs	5105	SF	0.25	$/SF	1,500
+ Roofing Membrane & Insulation	5105	SF	8	$/SF	40,840
+ Tacking and Accessories	5105	SF	2	$/SF	10,210
+ Irrigation					2,500
				PRICE	***$396,315***

From this analysis, the initial cost differences can be found of all three design variations. Below is an estimated table (Table 4) of the cost of each system for all roofing systems with the difference of cost from the current design. The difference was found by subtracting the current systems cost from the proposed systems cost.

Table 8: Initial Cost Comparison of All Three Roofing Systems

	Current Roofing System	**Relocation with Hydrotech**	**Relocation with XeroFlor**
Initial Cost	$422,400	$466,300	$396,300
Difference		$43,900	-$26,100

By changing the design to use a cool roof on the boiler/chiller building and the flat main roof with the Hyrdrotech green roof system on the front sloped roof the cost of the project is greatly increased – about $43,900 more than the current design. In this situation, the Hydrotech system is more costly than the metal roof system and the difference between the current green roof and the cool roof replacement.

As seen in the table, the owner can initially save around $26,100 dollars by using a cool roof system on the boiler/chiller room building and the main flat roof and by using the Xero Flor green roof system on the front sloped roof. In this situation, the Xero Flor system is less costly than the metal roof system and the difference between the current green roof and the cool roof replacement.

Additional consideration has been given for the yearly costs savings related to the energy savings of each design. First, the thermal resistance and solar heat gain loads on the varying designed roofs were translated into a yearly energy cost on the mechanical equipment. Based on the current average cost of electricity (per kWh), the heat flow rate of all three systems can be converted to the operating costs of the mechanical equipment for a portion of the building envelope cooling loads. Appendix C contains the operating costs calculation for all three systems. Below is a table of the yearly operating costs of the mechanical equipment for all three systems. The table also demonstrates the difference in costs from the current design.

Table 9: Yearly Mechanical Equipment (Partial) Operating Costs (Thermal and Solar)

	Current Roofing	Relocation with Xero Flor	Relocation with Hydrotech
Yearly Operating Costs	$15,680.00	$14,530	$14,480
Difference		-$1,150	-$1,200

By redesigning the slope roof with either green roof system, the operating costs of the mechanical equipment can be reduced each year by about $1,000 dollars.

Conclusions and Recommendations:

From the stand point of the Owner, Geisinger Health System may feel hesitant in making roof on the front façade green and in reality, the decision is theirs to make. The aesthetics and architecture of the building create the image of Geisinger so moving the green roof may be risky in the eyes of the Owner. Financially, the Owner can select the most cost effective solution – the Xero Flor Green Roof System – and save a substantial

initial amount ($26,000 savings), and they would incur slightly lower utility costs per year ($1,000 savings).

In regards to the project schedule, all of the roofing systems analyzed would either require extra training time for green roof installers or require extra time during installation for the intricate metal detail connections. Additional time to install a green roof may be necessary for the irrigation system installation and connections to a collection system.

Structurally, the Xero Flor System has a greater weight (by about 8 psf) and may require a slight redesign of the structural beams and columns below this portion of the roof. However, this structural redesign was not completed for this analysis.

With little technical information available regarding green roofs, it becomes difficult to give the best thermal and solar analysis possible. Conceptually, green roofs should reduce cooling loads dramatically from evaporation, radiation, and conduction, but calculating the evaporative cooling to exact numbers is very challenging.