DESALES
UNIVERSITY

SENIOR THESIS

Rev. James G. Gambet
Center for Business and Healthcare

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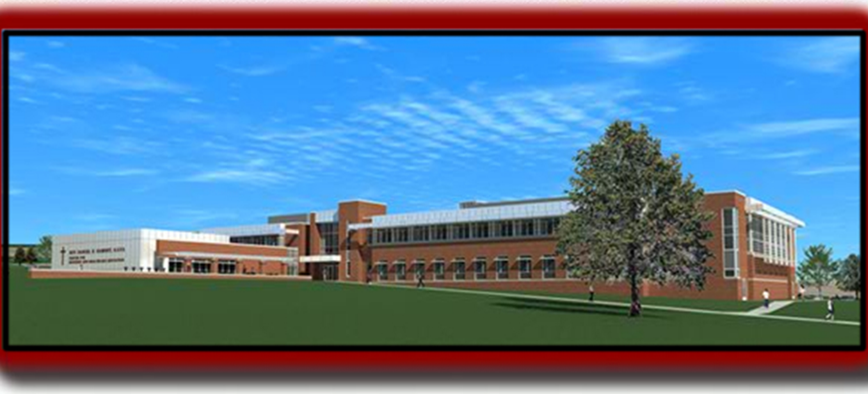
04.03.2013

Rev. James G. Gambet
CENTER FOR BUSINESS AND HEALTHCARE

DESALES UNIVERSITY
CENTER VALLEY, PA



BUILDING STATISTICS

size	77,000 square feet
cost	$27 million
number of floors	2 floors above grade
project delivery	Design-Bid-Build (CM-at-Risk)
construction dates	June 2011 - November 2012
occupancy	Business (B)

PROJECT TEAM

owner	DeSales University
architect	Breslin Ridyard Fadero Architects
construction manager	Alvin H. Butz, Inc.
mechanical/electrical	Snyder Hoffman Associates
civil/structural	Barry Isett Associates
LEED® consultant	7group

ARCHITECTURE

The Gambet Center was designed to be a state of the art facility that incorporates high levels of technology in the classroom while maintaining an emphasis on sustainability and healthy occupancy. An open lobby and seating area creates a welcoming feeling conducive to interaction outside the classroom. All faculty offices are located on the exterior of the building to provide expansive windows with an abundance of natural sunlight. A red brick exterior with limestone trim was used to retain a similar look to other DeSales buildings, with composite aluminum wall panels to give the Gambet Center a unique style on campus.

BUILDING SYSTEMS

STRUCTURAL

- 4” slab on grade foundation
- Two story structural steel frame
- 3-½” floor slab on 1-½” steel metal deck
- Built up EPDM roof membrane on 1-½” steel roof deck

MECHANICAL

- Combination air and water based systems
- Two natural gas fired water boilers
- Eight packaged gas fired VAV rooftop units (four with heat recovery) for heating and cooling
- High efficiency units for LEED® accreditation

ELECTRICAL

- 12,470V feed from campus substation to exterior 480/277V transformer
- Incoming 480/277V, 3 phase power
- 2000 amp switchboard with 480/277V distribution with 208/120V step down transformer
- Two natural gas fired emergency generators (100 and 70 kW)

EXECUTIVE SUMMARY

The Reverend James G. Gambet Center for Business and Healthcare is the latest addition to the campus at DeSales University. The new $27 million facility, which is the new home of the Business, Nursing, and Physician Assistant Programs, is state of the art and includes technologically advanced labs and classrooms. DeSales' continual growth and ever increasing quality in education has caused these programs to reach their maximum potential in the current facilities. Construction of the 77,000 square foot building is managed by Alvin H. Butz, Inc., and was completed in January 2013.

DeSales University has recently made large strides to integrate practices in sustainability throughout the campus, and the McShea Student Center was the University's first LEED® rated building. The Gambet Center is expected to achieve 50 LEED® credits to achieve a Silver rating. Four technical analyses in energy modeling, green roof implementation, on-site renewable energy, and advanced lighting controls were conducted to evaluate the building's potential to obtain 10 additional LEED® credits to be awarded a Gold status.

TECHNICAL ANALYSIS I: CONCEPTUAL ENERGY MODELING

The minimal use of Building Information Modeling on the project led to an opportunity to reduce The Gambet Center's energy consumption. Through utilization of Autodesk Project Vasari, it was determined that early use of energy modeling to compare alternative design options would have been effective in reducing energy costs. The software's energy analysis tool calculated an annual savings of $7,990 when reducing exterior glazing from 38 to 25 percent of the total area of the envelope. A savings of $13,434 was also estimated when considering a ground source heat pump for the HVAC system instead of the as-designed packaged gas VAV system.

TECHNICAL ANALYSIS II: GREEN ROOF IMPLEMENTATION

The Lecture Hall of the Gambet Center was originally an alternate bid, the inclusion of which requires two additional rooftop air handling units. A new 5,855 square foot green roof consisting of GroRoof™ hybrid green roof modules was designed. A structural breadth determined that the currently designed structure provides ample support for the added structural load of the system. A mechanical analysis estimated an annual savings of $147.68 in cooling costs. Grouped with tax incentives and an extended 40 year service life, the system will pay itself back in 25 years with a $22,263 return on investment. The low energy savings of the implementation suggests negligible effect on energy efficiency of the building, and as a result, no LEED® credit gains are expected.

TECHNICAL ANALYSIS III: ON-SITE RENEWABLE ENERGY

A combination rooftop and parking lot canopy photovoltaic array was considered in this analysis to generate 13 percent of the building's electricity to achieve 7 LEED® credits. The proposed 193 kilowatt system was determined to produce 220,894 ($21,206) kilowatt hours per year, equivalent to 26 percent of the building's power usage. Tax incentives and Solar Renewable Energy Credits also help to pay for the system in the 22nd year of the 25 year lifespan. The goal of 13 percent was doubled, and therefore a more economically feasible system is recommended that has a 15 year payback period and a 21 percent return on investment.

TECHNICAL ANALYSIS IV: ADVANCED LIGHTING CONTROLS

The original design of the Gambet Center includes a centralized Lutron Quantum® Total Light Management lighting control system. An expansion of this system to include the faculty offices, breakout, and conference rooms was studied to determine energy savings and effect on the LEED® rating. Although the upgraded system reduces the lighting load by 8 percent, the energy savings were not enough to obtain additional LEED® credits. Regardless of the unchanged LEED® rating, the system is recommended for implementation due to its low cost, 5 year payback period, and a lifetime return of $13,471.

When combining the effects studied in the technical analyses, and evaluating the effect on the LEED® rating of the building, it is not possible to achieve Gold with these solutions. When considering use of certified wood with a 10,000 gallon rainwater harvest system, the 3 available LEED® credits can be obtained to reach Gold. Alternatively, the unfavorably expensive ground source heat pump option investigated in Technical Analysis I can be implemented for an estimated cost increase of $584,440. This correlates to a gain of 6 LEED® points, which easily achieves a Gold rating.

ACKNOWLEDGEMENTS

ACADEMIC

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Moses Ling

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INDUSTY

DeSales University – Mark Albanese, Jim Molchany

Breslin, Ridyard, Fadero Architects – Dan Hersh

Alvin H. Butz, Inc. – Todd Rothermel

Lutron Electronics Co., Inc. – Ed Felegy, Bret Hoover

MGV GroRoof™ – Zach Williams

FAMILY AND FRIENDS

TABLE OF CONTENTS

PROJECT BACKGROUND

The Reverend James G. Gambet Center for Business and Healthcare is the latest addition to the campus at DeSales University. The new $27 million facility, which is the new home of the Business, Nursing, and Physician Assistant Programs, will be state of the art and include technologically advanced labs and classrooms. DeSales' continual growth and ever increasing quality in education has caused these programs to reach their maximum potential in the current facilities. Construction of the 77,000 square foot building is managed by Alvin H. Butz, Inc., and is scheduled to complete in November 2012.

Within the last five years, DeSales University has made a major push into educating students and facilitating sustainable practices. Through combining the business and healthcare departments into one building, they are exposing the medical students to the business side of their industry, while providing them all with a new building that promotes sustainability and healthy lifestyles. The Gambet Center is expected to obtain a certification of LEED® Silver.

Currently, the Gambet Center is eligible for 50 LEED® credits, the minimum amount necessary for a LEED® Silver rating. An additional 10 credits are required for the building to achieve an upgraded rating of LEED® Gold. Of the available credits that are applicable to the Gambet Center, a focus on the energy efficiency and consumption of the building is essential to discover techniques in which LEED® Gold can be attained. It is the intent of the following four technical analyses to propose options in which a Gold rating can be made possible.

PROJECT SCHEDULE SUMMARY

OVERVIEW

The project schedule for the Gambet Center is one of the main forces influencing the construction of the facility. DeSales University wants the building to be completed by the end of the Spring 2013 semester, so the construction sequence of the Gambet Center provides a loose schedule to account for any delays or unforeseen conditions, in addition to allowing for ample time for the Business, Nursing, and Physician Assistant Departments to move in.

SITEWORK

There is a total of 28 days from the Notice to Proceed (NTP) to the time the work on erosion and sedimentation (E&S) controls on site begin. During this mobilization period, temporary fencing and utilities, jobsite trailers, and parking areas will be installed on site. Then the topsoil will be stripped and stockpiled for future use. The installation of a new road, tentatively named Loop Road, will also be constructed. During this phase, the first 200 feet of Loop Road will be completed, and will eventually connect to opposite ends of Station Avenue to provide easy access to residence halls, the Connelly Chapel, and the Gambet Center.

EXCAVATIONS AND FOUNDATIONS

Immediately following mobilization and preparation of the site, excavation for the concrete footings will be performed. Simultaneously, the concrete footings will be formed and poured as the excavation continues. As the footings set, the foundation walls are built. Then the underslab utilities are installed, and the superstructure begins to be erected. .

SUPERSTRUCTURE

After structural steel is fabricated and delivered to site, the erection of the two-story moment frame starts to be placed. During this time, the steel deck is installed, along with the pouring of concrete slab-on-grade and floor slabs. This is followed by construction of roof blocking and EPDM membrane.

ENCLOSURE

Exterior steel studs and sheathing are installed and the masonry façade is erected. The Alucobond® exterior aluminum wall panels are prefabricated and shipped to site. During this time, the aluminum curtain wall and glazing are also connected to the structural steel frame. The built-up roof will be simultaneously constructed and is comprised of metal roof decking, rigid insulation, asphalt waterproofing, and vent flashing, Once completed, the building is permanently enclosed and work on interior finishes can begin.

INTERIOR

Before the building reaches full enclosure, interior framing, stairs, and MEP and fire protection systems are roughed-in. Once enclosed, construction on drywall, ceiling grids, ceramic tile, and terrazzo floors, and carpet are completed. Drop ceilings and MEP fixtures, such as lavatories, sinks, faucets, switchgear, and HVAC grilles and registers are put into place.

SUBSTANTIAL COMPLETION AND OCCUPANCY

The Gambet Center will reach substantial completion after final exterior grading, sidewalks, parking lots, and landscaping are finished. Commissioning of the various systems inside the building must also take place. Once this milestone is reached, various technological systems will be installed and furniture will be placed. DeSales is now ready for occupancy, while LEED ® ATC Commissioning takes place, and the building reaches final completion.

BUILDING SYSTEMS SUMMARY

Summaries of the various systems that make up the Gambet Center are detailed following the Building Systems Checklist, Table 1, below.

BUILDING SYSTEM CHECKLIST		
WORK SCOPE	YES	NO
Demolition		●
Structural Steel Frame	●	
Cast in Place Concrete	●	
Precast Concrete		●
Mechanical System	●	
Electrical System	●	
Masonry	●	
Curtain Wall	●	
Support of Excavation		●

Table 1 : Building Systems Checklist

STRUCTURAL STEEL FRAME

The structural steel frame consists mostly of two-story columns extending from the top of the footing or pier up to the roof. Wide flanged steel beams, spaced at 6' 8", support the second floor with a 1-½", 20-gauge metal deck that is topped with 3-½" of reinforced (W2.9xW2.9 WWF) lightweight concrete. Roof framing is comprised of a combination of wide flanged steel beams with open web steel joists ranging from a depth of 10" to 24", usually spaced at 5'. Roof decking consists of 22 gauge, 1-½" steel deck and a single-ply EPDM covering over rigid insulation tapered at ¼" per foot toward the roof drains. On site, a single crawler crane sized at 110 tons was used to erect the steel frame.

CAST-IN-PLACE CONCRETE

In addition to all strip, step, and column footers, the Gambet Center required reinforced cast-in-place concrete for foundation walls, column piers, slab-on-grade, and floor slabs. The altitude of the slab-on-grade is 473' above sea level. This is roughly the natural height of the east side of the building, which slopes down to the west to roughly 460'. However, the top elevations of the different footings vary east to west from 471.67' to 462', respectively. Therefore, most of the excavation took place on the east side of the building, but there was approximately 3' of soft surface soils that also required excavation on the west side. Plywood formwork was used for the cast-in-place foundation walls and column piers. The concrete was pumped into these forms in shallow lifts not greater than 24", and mechanically vibrated to consolidate; ensuring concrete is evenly distributed into corners and worked around reinforcement. The interior of the new foundation is then evenly backfilled to an elevation of approximately 472.33' and topped with at least 4" of drainage fill (gravel or crushed stone). Once erection of the steel columns began, the 4" slab-on-grade, covering a vapor barrier and welded wire fabric reinforcing was placed within the construction joints. Figure 1 below shows the excavated foundation and constructed cast-in-place and CMU foundation walls. The second floor metal decking provided the form for the floor slab, and the concrete was placed in a similar manner to that of the slab-on-grade.

Courtesy of DeSales University

Figure 1: Footing Excavation and Constructed Foundation Walls

MECHANICAL SYSTEM

The Gambet Center for Business and Healthcare is a state of the art facility that has a variety of uses, with additional requirements for thermal comfort and indoor air quality. To fulfill these needs, the HVAC system is comprised of a combination of air and water based systems. Located in the first floor mechanical room, two hot water boilers fired by natural gas and powered by two variable speed pumps supply heated water to all heating equipment in the building.

Packaged gas fired VAV systems, located on the roof, will provide heated air to the faculty offices, physician assistant (PA), business and nursing administration suites, the standardized patient exam suite, and basic nursing/PA labs, in addition to the lounge area, lobby, and corridors. Rooftop central air handlers supplying air to VAV energy recovery units deliver either heated or cooled air to areas requiring large amounts of outdoor air (classrooms, seminar rooms, lecture halls, and conference rooms). A gas fired constant volume heat recovery unit, also placed on the roof, heat the anatomy lab. For the remaining areas, such as toilets, stair towers, and vestibules, comfortable hydronic heaters are implemented.

For air conditioning, the aforementioned rooftop and heat recovery units will be equipped with cooling coils that supply chilled air to all areas except mechanical spaces, restrooms, and custodial closets in the same way as described above. For areas along the perimeter of the building, fan powered VAV boxes with a reheat coil are utilized. The interior spaces use VAV boxes with reheating coils, but these are be fan powered. Exhaust systems are not required, except for the toilets and mechanical room, since the implemented system conditions with a percentage of outdoor air. Automatic temperature controls are connected to the existing Campus Building Automation System, and give direct electric damper and valve control.

To help attain LEED® accreditation, the boilers will be 94 percent high efficiency units, and all VAV boxes contain electronically controlled motors, helping to save energy. All hot water piping is wrapped with fiberglass insulation, and the cooling coils in the rooftop units contain R410A refrigerant, also helping to achieve LEED® credits. To gain credits for thermal comfort, all offices except corner offices share a single fan powered VAV box.

ELECTRICAL SYSTEM

The Gambet Center receives its electrical power from the existing campus distribution system from the S&C PMH (pad mounted gear) switch, positioned to the south of the University Center. Existing empty underground conduits run from the PMH and extend to the south under Station Ave. A new 12,470-volt service will connect to these existing conduits and feed a 480/277-volt exterior transformer located near the service area on the east side of the building, and enter into the switchboard in the mechanical room.

In the 2000 amp switchboard, incoming power is metered and fused, and then distributed to equipment requiring 480/277 volts of power. This includes all mechanical equipment (480V or 277V) and the lighting system (277V). A 208/120-volt transformer is also included in the switchgear to source the receptacles (120V) and any equipment requiring 208V.

Two natural gas fired emergency generators (100 kW and 70 kW) are provided, and also housed in the mechanical room on the first floor. The 100 kW generator is connected to two automatic transfer switches, one that will power the anatomy lab's heat recovery unit, and the other for lighting, controls, and the fire alarm system. The third ATS, connected to the 70 kW generator, will provide emergency power for two air-cooled chillers and the two air handling units in the computer room. The uninterruptible power supply (UPS) in the will also receive emergency power in order to keep the computer systems from shutting down.

MASONRY

Depicted in Figure 2 on the right, the wall section shows the building enclosure of red face brick, with a 1-½” air cavity, 1-½” cavity wall insulation, and ½” sheathing on a 6” structural steel frame. Variances to this basic structure occur in the stair towers and mechanical room, where the brick veneer is backed by CMUs, with 2” cavity wall insulation. Masonry ties are used to connect the brick veneer to the exterior sheathing. Limestone is used for all sills, trim, and banding to compliment the brick. 8” CMUs are also used in the construction of a portion of the foundation walls, which can be seen in Figure 2.

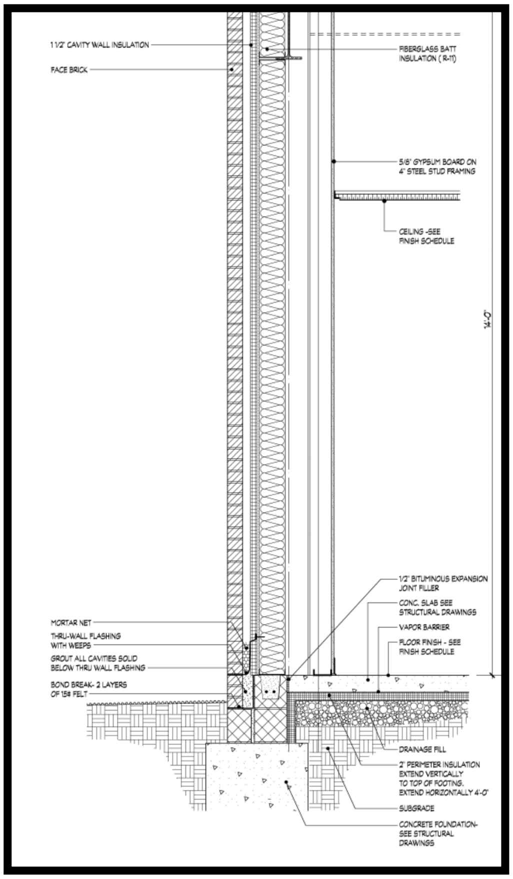


Figure 2: Brick Veneer Facade Construction

CURTAIN WALL

All exterior glazing consists of extruded aluminum curtain wall, either 6” or 7-½” deep as required. 1” thick insulating glass is used, with no operable windows. The aluminum doors are constructed similarly with extruded aluminum and 1” insulating glass. Horizontal sunshades are supported by a galvanized structural steel frame. The aluminum frame of the curtain wall is supported by steel connectors, supplied by the manufacturer, and attached the structural steel frame. Movable lifts are then used where required to assist in the attachment of second story curtain walls.

SUPPORT OF EXCAVATION

Due to the shallow foundation of the Gambet Center, a one to one slope of the excavated walls was sufficient to ensure both the integrity of the excavation and, in this regard, safety on site.

Groundwater was only discovered by the geotechnical evaluation at an altitude of approximately 450'. As this is sufficiently below any excavation on the site, dewatering will not be necessary. In addition to typical erosion and sedimentation controls, however, the site work package for the job includes an extensive storm water and drainage system to be completed in three phases over the course of construction.

CLIENT INFORMATION

Before being renamed in 2001, DeSales University was originally founded in 1964 as the Allentown College of St. Francis de Sales. Since that time, DeSales has transformed from an initial enrollment of 156 students with two unfinished buildings on a vast cornfield to a sprawling campus with over 1500 students and 23 large structures. By choosing to construct the Gambet Center, DeSales is continuing their growth by ensuring it does not reach its maximum acceptance of 1600 students. The building also sets a milestone of enabling DeSales to offer its first doctoral degree in chemical nursing. The quality of the business, nursing, and physician assistant (PA) programs has been constantly improving over the last decade. Through this continual improvement, DeSales has seen the functionality of their existing facilities reach an upper limit. The Gambet Center now allows the students of these programs to get the most out of their education, and in turn facilitates achieving new levels of excellence within the University.

One major concern with respect to the practicality of getting this project off the ground was cost. Although the college enjoys a $34 million endowment, in order to achieve the goals described above, the Gambet Center must include state of the art technology to foster students' continued development by putting the business, nursing, and PA departments in a position of leadership to positively change in the community. For this, Pennsylvania awarded DeSales with a $7 million Redevelopment Assistance Capital Program grant for construction projects that, among other things, encourage employment and other economic activity. DeSales believes the Gambet Center will better showcase these programs and attract more students and become an agent for growth. To a lesser extent, schedule is also a driving factor on the project. The University plans to open the doors to the public in May 2013, and since the Gambet Center is scheduled to reach substantial completion in November 2012, there is a good chance DeSales' move in date will not be affected by any unforeseen circumstances. DeSales chose Butz for the project based on their long-standing working relationship since the founding of the college. Therefore, both parties are confident in each other's ability to successfully complete the project.

While one of every owner's top priorities is the quality of the finished product, due to their previous experiences, DeSales has every assurance that Butz will deliver again. More recently, the University has become a strong proponent of introducing many green initiatives across the campus. In 2010, the new McShea Student Center was the first building at DeSales to become certified LEED® Silver. For these high principles in sustainability, the Delaware Valley Green Building Council awarded DeSales University with the 2011 Lehigh Valley Green Campus Sustainability Award. It should come as no surprise that this would set the bar for all new construction on campus. Alvin H. Butz, Inc. has incorporated LEED® in many new projects, has over 20 LEED® certified professionals on its staff, and is sure they can achieve a LEED® Silver rating with the Gambet Center.

LEED® EVALUATION

**Please see Appendix A for the LEED® 2009 New Construction and Major Renovation Scorecard*

DeSales University has recently become a strong proponent of green practices in sustainability by introducing a variety of initiatives across the campus including university wide recycling, student education, and sustainable building practices. Awarded with the 2011 Lehigh Valley Green Campus Sustainability Award, DeSales is proving the effectiveness of their green programs. In 2010, the McShea Student Center was the first building to obtain a LEED® Silver Certification. The Gambet Center is also designed to achieve an equal certification to maintain the University's position in the region as a leader in sustainability.

The United States Green Building Council (USGBC) implemented the first metric to analyze the incorporation of sustainable practices in new construction in 1998. The system has since evolved into a more comprehensive program awarding points on various categories including sustainable sites, water efficiency, energy and atmosphere, indoor environmental quality, innovation in design, and regional priority credits. Based on the requirements set by the owner and the constraints of the building, the project team can assess which LEED® credits are necessary, optional, or impossible to achieve a certain certification.

The complete LEED® Evaluation analysis is located below; specifically describing how the Gambet Center hopes to receive a silver certification. Please see Appendix A-1 for the LEED® 2009 New Construction and Major Renovations Scorecard.

SUSTAINABLE SITES

One constraint of the project is the building site. The location of the building was pre-planned per DeSales' Campus Master Plan, and therefore relocation of the Gambet Center was not possible in order to gain additional LEED® credits. Only 7 of the available 26 credits for this category can be pursued because of the limitations set by the site location. Four of these points are achieved through promoting sustainable transportation practices by providing showers to reduce driving elsewhere, four bicycle racks, and nine parking spaces dedicated to fuel-efficient vehicles. The remaining three credits are from implementing quantity and quality stormwater management controls and increasing the reflectiveness of the roof to reduce the heat island effect.

It is important to note that because the Gambet Center is located on an undeveloped, greenfield site; it is automatically disqualified from up to 9 points. Another major inhibitor of the Gambet Center performing well under the sustainable sites category is the lack of public transportation in the area. This excludes the building from receiving 6 LEED® points, and because of the rural location it is not likely that public transportation services will be provided in the near future. Local zoning requires a minimum number of parking spaces, which exceed the capacity defined by LEED®, which eliminates this credit for consideration.

Two areas of this category have potential to meet the requirements set by LEED®. An extra point can be obtained considering a change from paved to concrete parking lots, helping to reduce the heat island effect by increasing the reflectiveness of the material. Another point is available if the building does not add to light pollution. It is still unclear whether the minimum lighting requirements of the Gambet Center disqualify it from meeting this goal, however a further evaluation of the potential for earning this credit will be conducted if imperative for silver certification.

As described above, selecting a non-sustainable site can severely impact the ability to reach LEED® certification. If the site prevents a large gain of points in the sustainable sites category, the designers and project team must work hard to find ways to implement a large portion of credits from the remaining categories.

WATER EFFICIENCY

Out of the five main categories of LEED® 2009 for New Construction, water efficiency is the category with the least amount of possible points. Although only ten credits are available, the Gambet Center is able to acquire eight of these by using only non-potable water for landscaping, and by using low-flow plumbing fixtures to reduce water consumption by 40%.

The final two credits are available for innovative wastewater technologies, which are not currently considered for the Gambet Center. Rainwater collection and harvesting technologies that reduce potable water use for sewage by at least 50% can be considered to reach a perfect score for water efficiency. The high cost of the system relative to the gain of only two credits is probably the reason this system was not included on the project, but on the chance the building cannot meet the requisites for silver certification, there is potential to incorporate this solution.

ENERGY AND ATMOSPHERE

The Energy and Atmosphere of the LEED® 2009 Rating System is used to ensure a building is designed and operated to reduce energy consumption with regard to the environmental impacts associated with procuring the energy. Under Energy and Atmosphere, a total of 35 points are available. Energy and Atmosphere has the largest amount of achievable credits, which is a measure of the effect this category can have on the overall sustainability of the project.

Through a reduction in energy consumption, a maximum of 19 points can be obtained based on the percentage of improved energy performance over the baseline ASHRAE/IESNA requirements. High efficiency boilers, electronically controlled VAV boxes, and lighting control systems used in conjunction with mechanical pipe and exterior insulation, specialized glazing, and sun control devices help to reduce the Gambet Center's energy use by at least 18% – allotting 4 out of 19 credits.

An additional five points are awarded for enhanced commissioning, using R410A refrigerant, and by DeSales agreeing to share the building's energy and water usage with the USGBC through the ENERGY STAR® Portfolio Manager. The owner was not interested in including on-site renewable energy such as solar and wind power due to a high initial cost and unfavorable payback period of more than five years. For this reason, geothermal heat pumps were also not considered, leaving up to seven points unqualified for credit.

Two credits for providing at least 35% of the building's energy from green power are currently targeted by the architect to count towards LEED® accreditation. It is still unclear whether this requirement can be met, but the architect is soliciting proposals to use green sourced power on the job.

MATERIALS AND RESOURCES

The inherent energy consumed during construction accounts for a substantial portion of the total energy used over the lifetime of the building. Under Materials and Resources, methods of procuring sustainable, local materials and the handling of waste during construction are assessed. Up to 14 credits can be achieved through integrating these concepts into the building design and construction.

The Gambet Center receives two points for including a construction waste management plan that clearly identifies practices that save a minimum of 75% of construction debris from disposal. Through using 20% of recycled materials or materials manufactured within 500 miles of the building site, four credits are expected.

Because the Gambet Center is a new construction project, it is not eligible for six credits awarded to projects that reuse existing systems or materials. Credits for incorporating rapidly renewable materials are also not available for this project. It is uncertain if at least 50% of wood construction in the facility utilizes certified wood. The architect would only consider targeting this credit if costs were not greatly affected.

INDOOR ENVIRONMENTAL QUALITY

All buildings require some level of thermal comfort and indoor air quality, however, LEED® will award points to buildings that exceed these basic requirements set by code. Indoor Environmental Quality measures the extent to which an owner will go to provide users with a healthy environment by using non-hazardous materials and allowing individual control. A total of 15 credits are available for this category.

The Gambet Center reaches most requirements in this category, scoring ten points. Using non-toxic materials and coatings for all finishes contributes four points. The remaining credits are added by monitoring outdoor air delivery, indoor air quality management during construction and before occupancy, lighting control, and design and verification for thermal comfort.

The last five points not awarded are all due various limits set by the project. It is not logical to include user controlled ventilation as this increases HVAC loads and requires larger equipment, which in turn reduces efficiency and loses LEED® credits in the Energy and Atmosphere section. A MERV 13 filter is required to receive credits for indoor chemical and pollutant source control, but the filter is also not practical for the selected system for similar reasons. Three points for user temperature controls and daylighting/views are not included because there are not enough spaces in the building to meet LEED® requirements.

INNOVATION AND DESIGN PROCESS/REGIONAL PRIORITY CREDITS

The prior categories comprise the major ways available to construct a sustainable building. LEED® also recognizes that all buildings are not the same, and each project may have its own integration of green concepts in a unique way. Innovation and Design Process and Regional Priority Credits are the last two categories for LEED® certification. These provide the opportunity for six and four additional credits, respectively. In many cases, as it is with the Gambet Center, these categories decide what certification a project ultimately receives.

The Gambet Center was able to gain all six points for Innovation and Design Process. A comprehensive, university wide recycling program, user education program in sustainability, the use of blended cement, water bottle fill stations, and surpassing the 95% threshold for management of construction waste all provide opportunities for the Gambet Center to receive additional credits.

Regional Priority Credits were harder to obtain, and must show incentives that address region-specific environmental priorities. Two extra credits are targeted for the control of the quantity of stormwater and implementing construction waste management techniques to reduce at least 50% of waste. Again, the choice of a natural site restrains a lot of possible avenues to consider for Regional Priority Credits.

LEED® 2009 SCORECARD AND EVALUATION

The LEED® Scorecard included in Appendix A-1 shows the Gambet Center expects to achieve a total of 50 credits. This just barely reaches the cutoff and makes the building eligible for the targeted LEED® Silver certification. It's important to remember that the checklist scores points based on what is believed to be obtainable, and there is no guarantee all points speculated would be accepted during the review process. With a minimum of 50 points needed for LEED® Silver, a rejection of any credit places it down in the LEED® Certified category.

After evaluation of the scorecard, it can be predicted that all but two credits are likely to be accepted. The two credits that could possibly fail are the two awarded for using green power sources for 35% of electricity. The architect thinks this is possible, but if it is not the owner will not get the expected certification. It is advantageous to analyze the areas not originally targeted for credit to find ways to include them in the project. It is best to start out with the most cost-efficient options, until it is necessary for the owner to decide how much they are willing to spend to receive the desired LEED® Rating.

A point could be added to sustainable sites if the paved parking lots were changed to concrete. Concrete surfaces have a higher initial cost, but can last longer if properly maintained. The freeze/thaw cycle in the area makes maintaining concrete a challenge, and is probably not the best option for getting additional points. If the building proves to not add to light pollution, another point could be awarded, but due to the campus environment and site lighting requirements, this is also not likely.

The final options to consider when trying to gain additional LEED® credits are more expensive to implement. Depending on the level of incorporation, on site solar panels could be installed to produce at least 3% of the energy requirements to obtain two credits. A higher portion of on-site renewable energy reaches a maximum of seven points (13% renewable energy). Two additional points can be granted by improving the energy efficiency of the building by at least 4%. The last option would be to install a rainwater collection and harvesting system to use less potable water for sewage.

These options all have a high initial cost to implement, but improving energy efficiency and producing on-site power have payback periods. The rainwater harvesting may possibly have a lower first cost, but future savings are not as significant, and lifecycle cost analyses help determine the best possible solution. The final decision is up to the owner, and it is not likely DeSales would invest in these options for LEED® rating alone.

Many considerations were made to reach the project goal to achieve LEED® Silver certification, but the final result depends on every projected credit to be accepted by the review board. Breslin Ridyard Fadero Architects remains confident the Gambet Center will obtain a minimum of LEED® Silver, despite only expecting to receive the minimum of 50 credits.

TECHNICAL ANALYSIS I: CONCEPTUAL ENERGY MODELING

PROBLEM IDENTIFICATION

Although high sustainable performance was the a requirement to the design of the Gambet Center, the use of building information modeling (BIM) was limited to the architectural massing and rendered images. The mechanical contractor also created 3D models of the mechanical system for their own constructability review, and there was no coordination with other trades. Had the early conceptual design of the building been integrated with energy modeling software, there could have been opportunities to make smarter decisions relating to the energy efficiency of the building.

RESEARCH GOALS

The use of conceptual energy modeling is helpful in the early design process to discover inefficiencies in the design. Although the Gambet Center finished construction in early 2013, the current design can be analyzed and compared to alternative options with modifications of various parameters. The creation of an energy model of the Gambet Center also aids in the completion of the other technical analyses by providing energy usage estimates that are difficult to obtain with the building not yet fully operational.

METHODOLOGY

- Choose energy modeling software to analyze the building
- Understand the application, features, and the limits of its functionality
- Create a conceptual model of the building and run an energy analysis
- Run additional analyses to compare with original design
- Suggest appropriate changes in design that improve energy usage

RESOURCES AND TOOLS

- Applicable Literature
- Video Tutorials
- Autodesk Project Vasari
- Department Faculty

EXPECTED OUTCOME

The LEED® Silver rating of the Gambet Center suggests a fairly high level of sustainable practices already integrated into the design. Explained in the LEED® Evaluation above, the Gambet Center performs poorly in the Sustainable Sites category. In order to reach the Silver rating, the other credits need to be achieved through other categories. This suggests that any improvements to the building will most likely be minimal, though it is expected that the results of this technical analysis will be able detail some improvement to the design.

BIM AND ENERGY MODELING

The last decade has been witness to a great increase in computer processing power. At the same time, the use of computer programs for building design, construction, and operation has evolved into a trend that is beginning to become standard practice throughout the industry. This digital representation of a facility's physical and functional characteristics is known as Building Information Modeling. Although the concept of BIM dates back to the 1970s, the necessary comprehensiveness of the software was not possible until the vast amount of information required could be processed. It is important to remember that BIM is not simply computer generated construction documents (CAD) of a building, but a process that often begins with a 3D building model in which information is embedded into the components. The model is only one aspect of BIM, which can also include structural design, 3D coordination, or 4D modeling. BIM has historically been most helpful with 3D visualization of a building, its components, and constructability reviews. More recently, BIM has evolved to aid with building simulation using 3D models that include steel properties to run structural analyses, scheduling information, maintenance scheduling, and energy simulations. Table 2 details many applications of Building Information Modeling. In terms of this technical analysis, the focus will remain on energy modeling.

Building Maintenance Scheduling	Digital Layouts
Building Systems Analysis	3D Coordination
Asset Management	Engineering Analysis
Space Management and Tracking	Facility Energy Analysis
Disaster Planning	Structural Analysis
Record Modeling	Sustainability Evaluation
Site Utilization Planning	Code Validation
Virtual Mockups	Cost Estimation
Digital Fabrication	Phase Planning
Programming	Design Reviews
Site Analysis	Existing Conditions Modeling

Table 2: BIM Uses

The term "energy modeling" refers to the use of computer based tools to simulate the energy use of a building, which is usually calculated on an annual basis. For new projects, and the emphasis of this analysis, this process should start in the conceptual design phase. Starting early in the design phase can give valuable insight into design decisions. Alternative design conditions such as building orientation, glazing area and shading, thermal performance, and solar analysis can easily be compared to determine the most efficient design. There are obviously many assumptions at this point in the design phase, and as such, the results are not always accurate. The conceptual models do prove to be adequate for comparing relative differences in design parameters.

AUTODESK PROJECT VASARI

Courtesy of autodeskvasari.com

The undergraduate Architectural Engineering curriculum incorporates a strong commitment to providing students with opportunities to receive training and experience using computer programs; specifically with the Autodesk AutoCAD, Revit, and Navisworks applications. Project Vasari is a conceptual energy design tool that is part of the Autodesk Labs initiative, an online environment where collaborative software development of prototype software based on new technology from Autodesk is created. Vasari is a second generation beta program based on Revit that allows for energy analysis of design concepts. Once an acceptable design is chosen, it can then be easily ported to Revit to simplify the modeling process as the design evolves.

Autodesk Labs is great because it involves customers and developers who can freely use tools developed by Autodesk that are too new and unreliable to become a product. Project Vasari, which also uses various tools from Green Building Studio and Ecotect, quickly became popular on Autodesk Labs and evolved into a beta program. Vasari has become refined enough that Autodesk will integrate energy simulation into the next version Revit, with the ability to run analyses on building components like walls and roofs for more accuracy. Although this software is too new to be considered in Technical Analysis I, it is exciting to be witness to the maturation of BIM technology.

The way Vasari works is to either create or import a mass model into the program. From here, the model's surfaces can easily be converted to walls, floors, and roofs. If necessary, Vasari can also create individual zones within the building. After creating the model, there are multiple inputs that need to be set in the program before the energy analysis can be completed. These parameters relate to the building location, form, envelope, function, and systems.

Location and Climate

It may seem obvious, but the location of the building very much dictates how its energy is consumed. The air temperature, humidity, and typical weather patterns all change based on the location. A university science building in the arid climate of Phoenix, AZ will use air conditioning most of the time, while the Gambet Center experiences drastic changes in temperature throughout the year and needs a combination of heating and cooling. The path of the sun is also dependent upon the location, which effects the solar heat gain and shading.

Building Form

The wall area exposed to the outside and the mechanical loads imposed on the envelope are affected by the form and orientation of the building. When creating the 3D model in Vasari, information regarding the building form is used to calculate the annual energy use.

Envelope

The building envelope acts like a membrane between the interior and exterior of the building. They are highly variable, and can be constructed in a variety of ways. This explains why Vasari needs data on the level of insulation, shading, glazing type, and window to wall ratio to report a more accurate energy simulation.

Use and Function

The type of building constructed usually gives a good idea of its use and function. Certain building types have similar spaces, occupancies, and schedules. All of these can impact the energy use of a building, and as such, Vasari allows these parameters to be refined for the analysis.

Building Systems

The energy requirements of a building's equipment, lighting, and HVAC systems are major contributors to its energy consumption. Vasari allows these system types to be specified and compared against each other to determine the most efficient system. Vasari does not provide any cost information, so it is the designer's responsibility to understand the owner's expectations and budget. Figure 3 shows Autodesk's interpretation of a Vasari energy model.

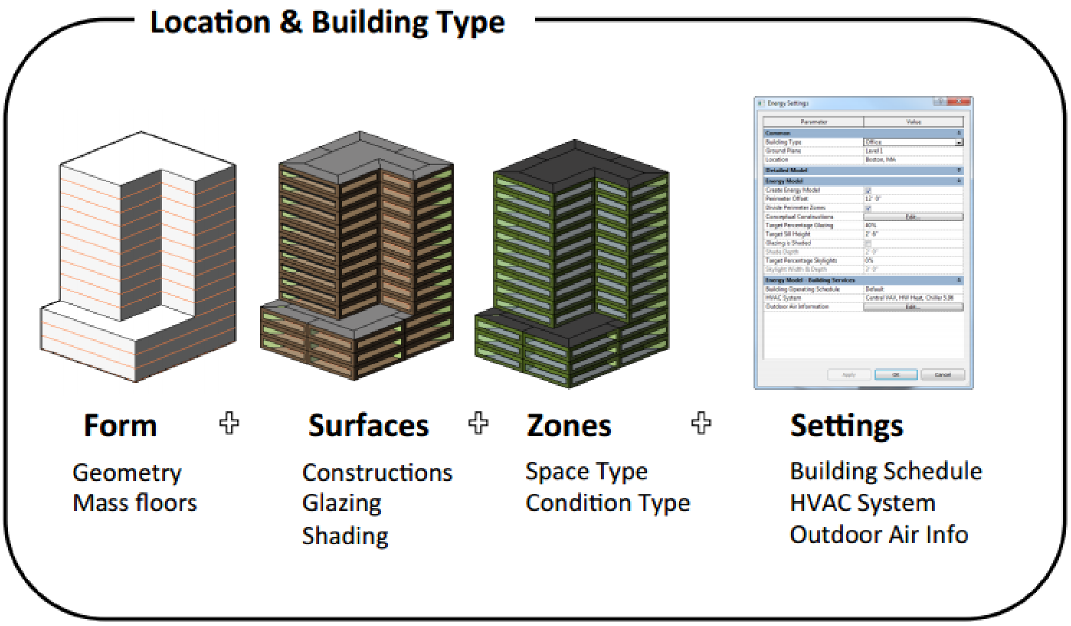


Figure 3: Autodesk's Anatomy of an Energy Model in Vasari

As stated above, it must be remembered that conceptual energy models are not always accurate and are used for comparative analysis. Therefore, it is good for use in the conceptual design phase for accepting or rejecting preliminary ideas. Although not typically used for absolute energy estimates, the lack of available data for Gambet Center requires the results from this study to be used in the forthcoming technical analyses.

ENERGY MODEL

Since a major advantage of using Vasari is its foundation in Revit, the energy model can be easily created using skills learned in AE 222: Working Drawings. The typical energy modeling process begins with either creating or importing a mass model. The Vasari application window contains a ribbon interface similar to that in other Autodesk programs and includes modeling, analysis, and management tabs. The model tab provides the traditional tools to create conceptual mass models to be analyzed. The mass model created for the Gambet Center can be viewed in Figure 4.

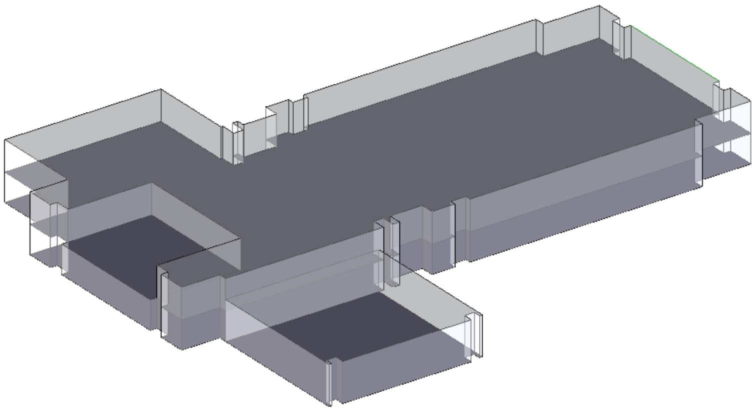
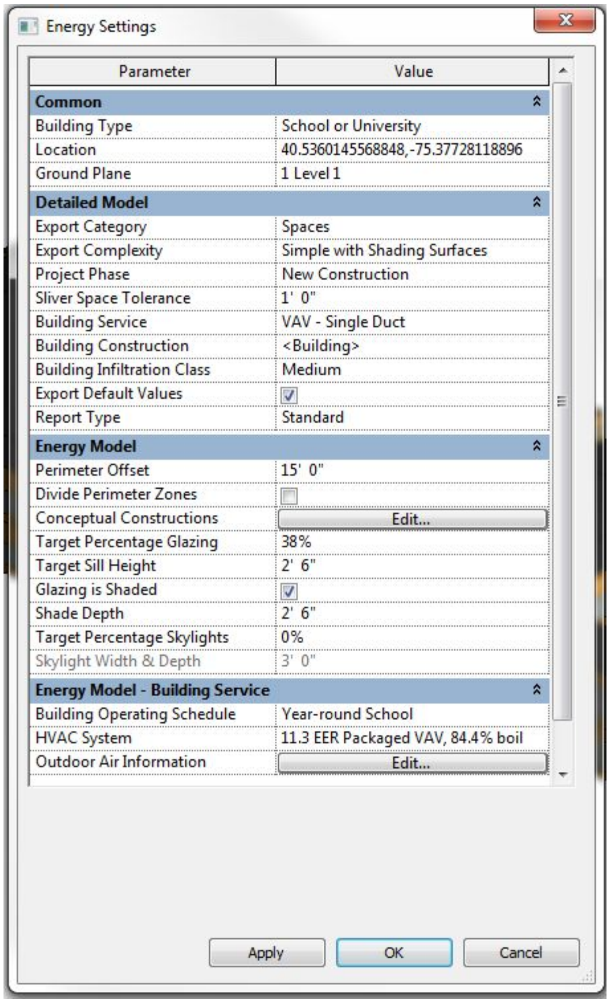
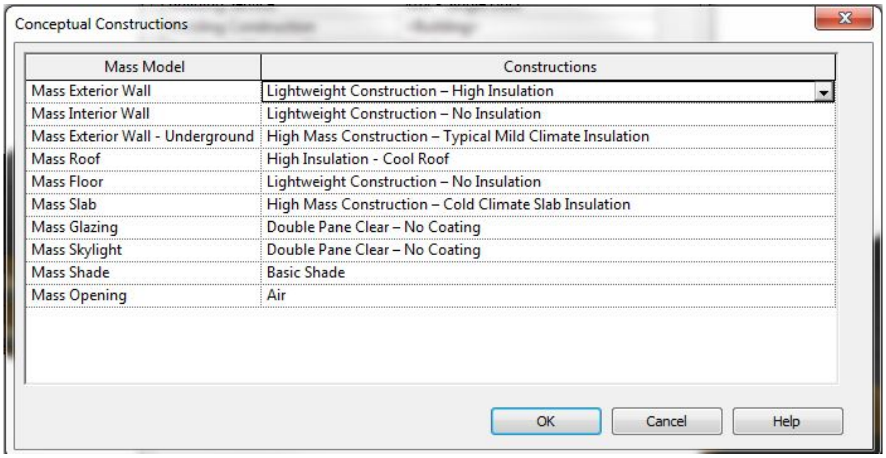


Figure 4: Mass Model of the Gambet Center

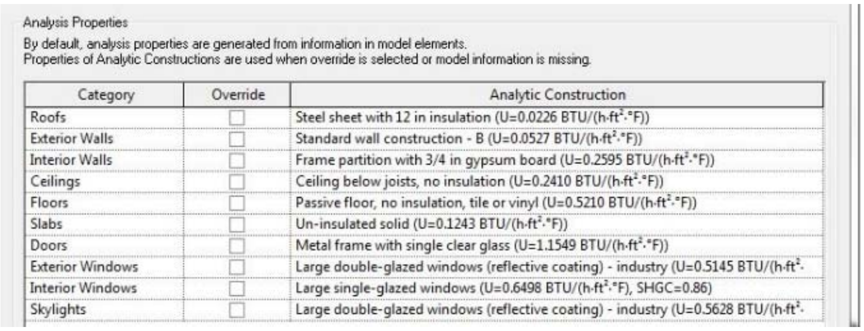
The management tab contains various program tools including window management, display options, and views. Also included are project and sun settings that allow manipulation of the variables of the energy simulation. Opening the project properties allows identifying data to be entered, but also has sub-settings for energy analysis. This is where many of the building properties are entered for the energy model. A screenshot of the Energy Settings Dialogue box is shown below for the final design of the Gambet Center. Settings for the conceptual construction of the building with more specific parameters are included with the screenshots in Figure 5.



Parameter	Value
Common	
Building Type	School or University
Location	40.5360145568848,-75.37728118896
Ground Plane	1 Level 1
Detailed Model	
Export Category	Spaces
Export Complexity	Simple with Shading Surfaces
Project Phase	New Construction
Sliver Space Tolerance	1' 0"
Building Service	VAV - Single Duct
Building Construction	<Building>
Building Infiltration Class	Medium
Export Default Values	☑
Report Type	Standard
Energy Model	
Perimeter Offset	15' 0"
Divide Perimeter Zones	☐
Conceptual Constructions	Edit...
Target Percentage Glazing	38%
Target Sill Height	2' 6"
Glazing is Shaded	☑
Shade Depth	2' 6"
Target Percentage Skylights	0%
Skylight Width & Depth	3' 0"
Energy Model - Building Service	
Building Operating Schedule	Year-round School
HVAC System	11.3 EER Packaged VAV, 84.4% boil
Outdoor Air Information	Edit...



Mass Model	Constructions
Mass Exterior Wall	Lightweight Construction – High Insulation
Mass Interior Wall	Lightweight Construction – No Insulation
Mass Exterior Wall - Underground	High Mass Construction – Typical Mild Climate Insulation
Mass Roof	High Insulation - Cool Roof
Mass Floor	Lightweight Construction – No Insulation
Mass Slab	High Mass Construction – Cold Climate Slab Insulation
Mass Glazing	Double Pane Clear – No Coating
Mass Skylight	Double Pane Clear – No Coating
Mass Shade	Basic Shade
Mass Opening	Air



Analysis Properties

By default, analysis properties are generated from information in model elements.
Properties of Analytic Constructions are used when override is selected or model information is missing.

Category	Override	Analytic Construction
Roofs	☐	Steel sheet with 12 in insulation (U=0.0226 BTU/(h·ft^2·°F))
Exterior Walls	☐	Standard wall construction - B (U=0.0527 BTU/(h·ft^2·°F))
Interior Walls	☐	Frame partition with 3/4 in gypsum board (U=0.2595 BTU/(h·ft^2·°F))
Ceilings	☐	Ceiling below joists, no insulation (U=0.2410 BTU/(h·ft^2·°F))
Floors	☐	Passive floor, no insulation, tile or vinyl (U=0.5210 BTU/(h·ft^2·°F))
Slabs	☐	Un-insulated solid (U=0.1243 BTU/(h·ft^2·°F))
Doors	☐	Metal frame with single clear glass (U=1.1549 BTU/(h·ft^2·°F))
Exterior Windows	☐	Large double-glazed windows (reflective coating) - industry (U=0.5145 BTU/(h·ft^2·
Interior Windows	☐	Large single-glazed windows (U=0.6498 BTU/(h·ft^2·°F), SHGC=0.86)
Skylights	☐	Large double-glazed windows (reflective coating) - industry (U=0.5628 BTU/(h·ft^2·

Figure 5: Energy Model Parameters

The energy model has now been updated to reflect the design of the Gambet Center. Once the location is set under the analyze tab, the building's form, construction, functionality, and systems have all been programmed for consideration in the energy model. When ready, the model is uploaded onto Autodesk servers where the simulation is processed remotely. The completed energy report can then be exported to PDF and reviewed. All energy model results can be located in their entirety in Appendix B.

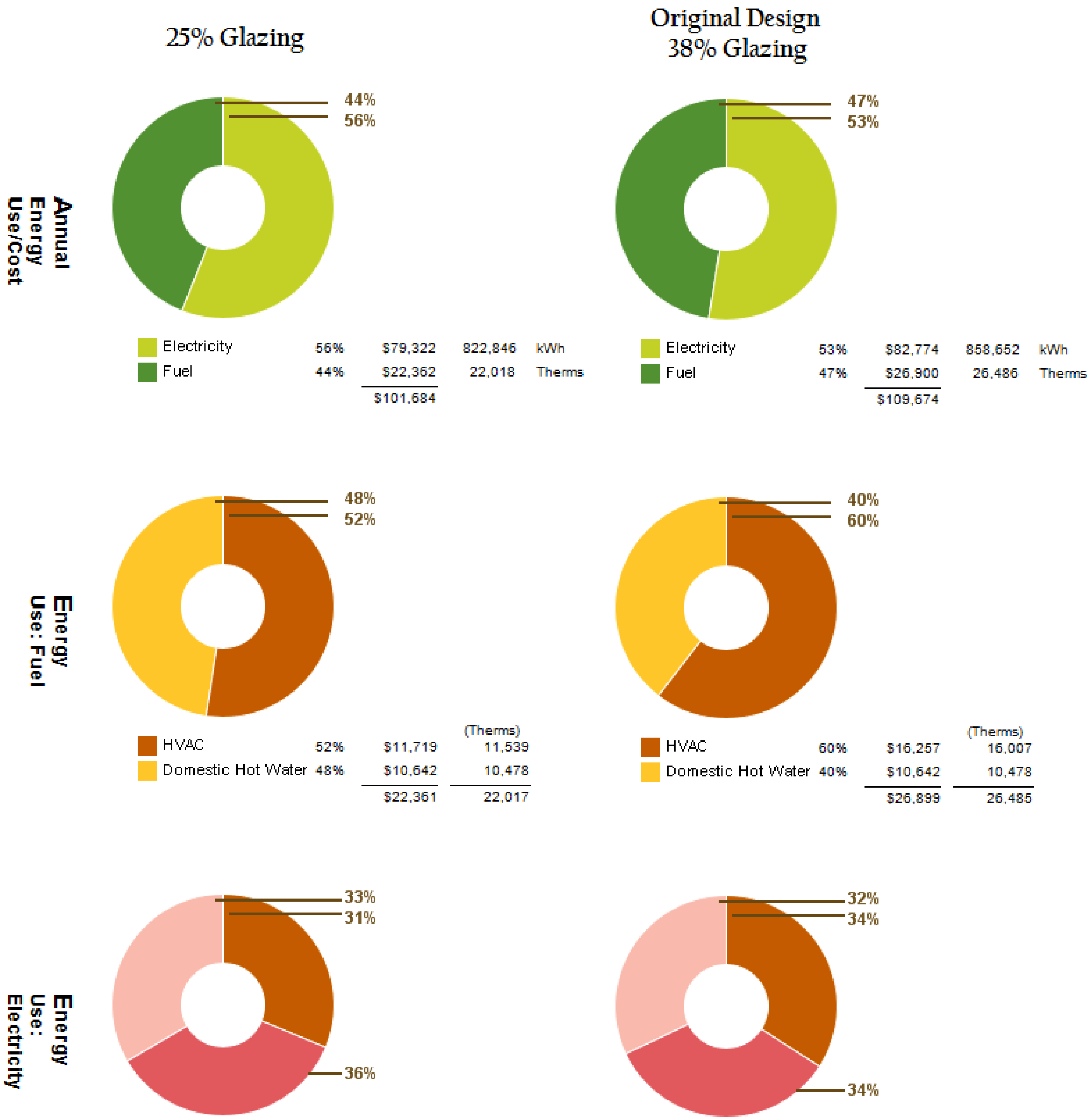
CONCEPTUAL DESIGN COMPARISON

The main benefit of energy modeling in the conceptual design phase is for comparative analysis between two design options. The architectural elevations revealed an approximate window area to total wall area ratio of 38 percent. In other words, 38 percent of the building envelope was comprised of glazing. While expansive glazing provides architectural beauty and an abundance of natural lighting, the thermal performance of the envelope is decreased. This effect is intensified when the walls are designed to have a high R-values. Another report can be created by modifying the previous energy simulation to reduce the amount of glazing to 25 percent of the exterior wall area. Project Vasari allows two reports to be viewed alongside each other for a quick comparison.

The results, which can be seen in Figure 6, show a decrease of 7.3 percent ($7,990) to the annual energy costs of the Gambet Center when reducing the glazing area. A more detailed review shows that the added efficiency is a result of a significantly lower mechanical load. This makes sense because the solar transmittance and low thermal performance of glass causes the heating and cooling loads to increase in the presence of larger windows. The reduced energy usage of the HVAC system is equivalent to a 30 and 12.3 percent decrease in natural gas and electricity consumption, respectively, for the system.

The Vasari energy analyses show no change in the lighting, hot water, or miscellaneous equipment. It is expected the energy used for domestic hot water and miscellaneous building equipment is independent of the amount of glazing; however, the reduction in window area would have an effect on the lighting system. Vasari's lighting analysis relies on the building type to provide the usage data, so as other parameters change, they show no effect on the energy use of the lighting system. This is a current limitation of the software, and is important to note. It is the designer's responsibility to understand less natural lighting is available with a reduction in window size. The lights would be turned on more often leading to an increase in annual electricity use. Hence, the energy savings described above would not be as substantial.

Another effect of Vasari obtaining lighting data this way is there are no settings to adjust to provide the program an indication of the properties of the lighting system. Further explained in Technical Analysis IV, Vasari does not take into account the sophisticated lighting design and control technology implemented in the building to cut power consumption. The Gambet Center has an actual lighting power density of approximately .78 watts per square foot, compared to 1.2 watts per square foot used for the energy analysis. Therefore, the annual lighting load is severely overestimated.



25% Glazing – Annual Energy Use/Cost

Electricity	56%	$79,322	822,846	kWh
Fuel	44%	$22,362	22,018	Therms
		$101,684		

Original Design 38% Glazing – Annual Energy Use/Cost

Electricity	53%	$82,774	858,652	kWh
Fuel	47%	$26,900	26,486	Therms
		$109,674		

25% Glazing – Energy Use: Fuel

			(Therms)
HVAC	52%	$11,719	11,539
Domestic Hot Water	48%	$10,642	10,478
		$22,361	22,017

Original Design 38% Glazing – Energy Use: Fuel

			(Therms)
HVAC	60%	$16,257	16,007
Domestic Hot Water	40%	$10,642	10,478
		$26,899	26,485

25% Glazing – Energy Use: Electricity

			(kWh)
HVAC	31%	$24,626	255,461
Lighting	36%	$27,855	288,962
Misc Equipment	33%	$26,369	273,546
		$78,850	817,969

Original Design 38% Glazing – Energy Use: Electricity

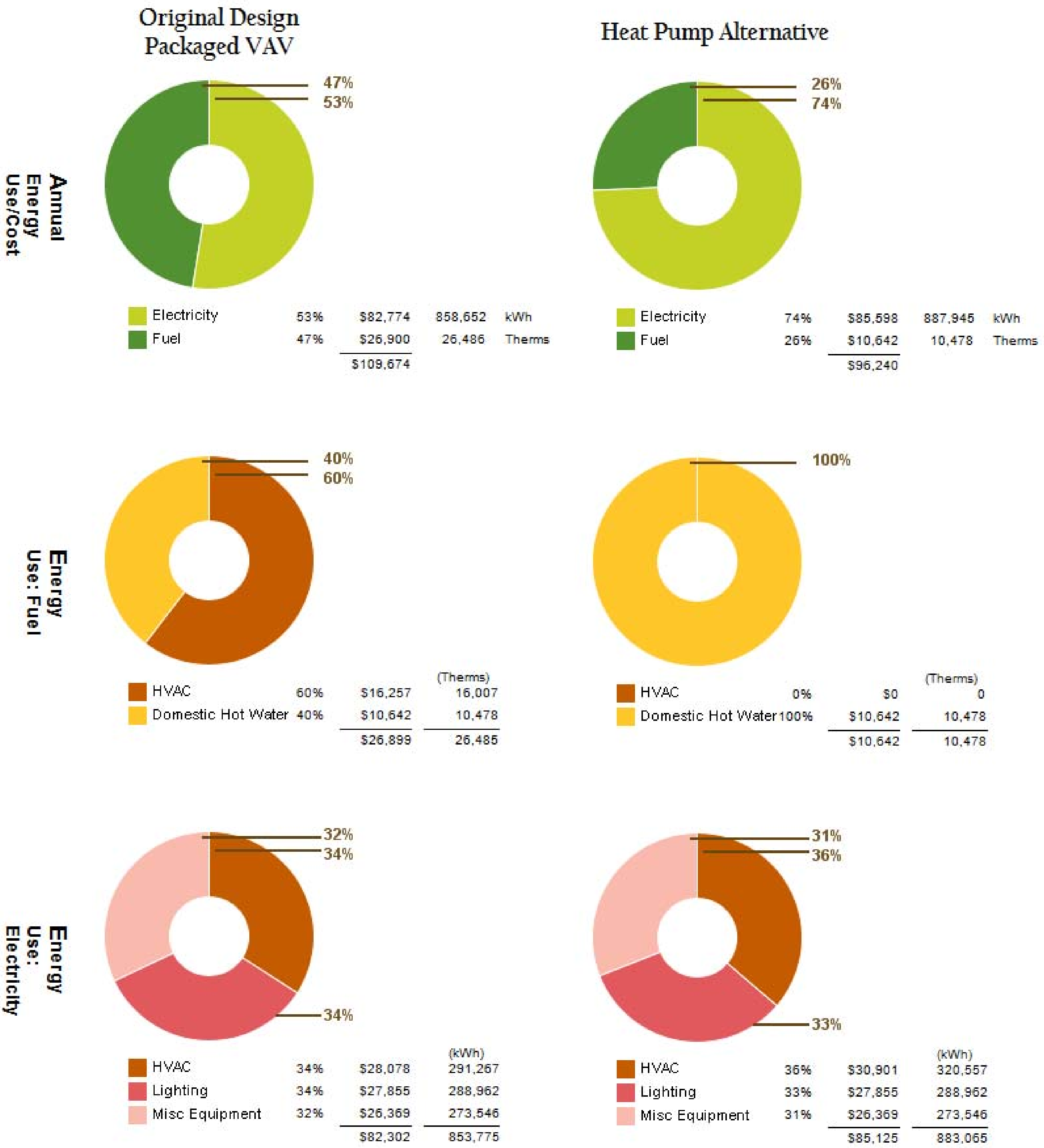
			(kWh)
HVAC	34%	$28,078	291,267
Lighting	34%	$27,855	288,962
Misc Equipment	32%	$26,369	273,546
		$82,302	853,775

Figure 6: Vasari Energy Analysis Comparison of 38% and 25% Glazing

Another Vasari report (Figure 7) was created to view the effect of upgrading the mechanical system from a package VAV system to a more efficient heat pump. As expected, the energy cost is significantly reduced due to the elimination of using natural gas for heating. Natural gas consumption of the HVAC system is reduced by 100 percent, with a 10 percent increase in electrical consumption.

In terms of whole building usage, the heat pump offers an estimated savings of $13,434 per year. The natural gas consumed by the building is 60 percent less when equipped with a heat pump mechanical system. A 60 percent reduction in natural gas paired with an increased electrical load of 3.4 percent shows a phenomenal improvement in efficiency of the building over the packaged VAV system.

Studying the Gambet Center revealed a thorough design in regard to sustainability, so it must be recognized that heat pumps are markedly more expensive than more traditional HVAC systems. They also require multiple bore holes to be excavated for the loops, which is also expensive and adds to the system cost. Although their energy efficiency is unmatched, the savings incurred are not always enough to pay for the system within its lifetime, and it is this reason this option was not used for the project.



Original Design Packaged VAV – Annual Energy Use/Cost

🟩 Electricity	53%	$82,774	858,652	kWh
🟩 Fuel	47%	$26,900	26,486	Therms
		$109,674		

Heat Pump Alternative – Annual Energy Use/Cost

🟩 Electricity	74%	$85,598	887,945	kWh
🟩 Fuel	26%	$10,642	10,478	Therms
		$96,240		

Original Design Packaged VAV – Energy Use: Fuel

			(Therms)
🟧 HVAC	60%	$16,257	16,007
🟨 Domestic Hot Water	40%	$10,642	10,478
		$26,899	26,485

Heat Pump Alternative – Energy Use: Fuel

			(Therms)
🟧 HVAC	0%	$0	0
🟨 Domestic Hot Water	100%	$10,642	10,478
		$10,642	10,478

Original Design Packaged VAV – Energy Use: Electricity

			(kWh)
🟧 HVAC	34%	$28,078	291,267
🟥 Lighting	34%	$27,855	288,962
🟥 Misc Equipment	32%	$26,369	273,546
		$82,302	853,775

Heat Pump Alternative – Energy Use: Electricity

			(kWh)
🟧 HVAC	36%	$30,901	320,557
🟥 Lighting	33%	$27,855	288,962
🟥 Misc Equipment	31%	$26,369	273,546
		$85,125	883,065

Figure 7: Vasari Energy Analysis Comparison of VAV and Heat Pump HVAC System

CONCLUSION

Utilization of Building Information Modeling is helping drive innovation in the construction industry through allowing more complex and collaborative designs that are beginning to integrate at a higher level with building simulation and operation applications. In this way, energy modeling has been refined to provide more accurate assessments of the energy use throughout buildings. Energy modeling early in the design process allows designers to analyze their conceptual designs to comprehend how small changes can affect efficiency.

Project Vasari is conceptual energy modeling software supported by Autodesk that has become popular due to its ease of use and tight integration with other Autodesk products. The reports generated for the Gambet Center show the decision to limit the window area to 25 percent of the building envelope reduces natural gas consumption by 30 percent and power by 12.3 percent. This modification results in a $7,990 annual savings for DeSales. Considering a heat pump over the original VAV system, an annual savings of $13,434 is achieved. Although 3.4 percent more electricity is consumed, the Gambet Center consumes 60 percent less natural gas when equipped with a heat pump heating and cooling system.

TECHNICAL ANALYSIS II: GREEN ROOF IMPLEMENTATION

PROBLEM IDENTIFICATION

The Lecture Hall was initially an alternative option to the initial design of the Gambet Center eventually included in the scope of the project. The alternate design requires two additional heat recovery units to meet the additional mechanical load. The implementation of a green roof system above the Lecture Hall may allow for a significant reduction to the mechanical load of the space, possibly leading to additional LEED® credits to help achieve a Gold rating.

RESEARCH GOALS

The goal of Technical Analysis II is to complete an in-depth study of green roofing systems for possible implementation above the Lecture Hall. The appropriate solution will be designed for the roof, and an analysis of the additional load of the system will be performed to determine the need for additional structural support. From here, the costs associated with the system will be calculated, and a lifecycle cost analysis will help determine the feasibility of implementation. A study into the effect the green roof system has on the LEED® rating of the building will be conducted with the hope that the system will help achieve a Gold rating. Ultimately, a recommendation will be given to the owner whether or not they would benefit from the implementation of a green roof above the Lecture Hall of the Gambet Center.

METHODOLOGY

- Research variations of green roofing systems to determine which types are most appropriate for the project
- Propose a design of the selected green roof system
- Structural breadth to analyze effect on the structural system, and determine what changes may be necessary
- Mechanical breadth to calculate reduction of HVAC load on the space
- Produce a cost estimate of the system and perform lifecycle cost analysis to determine payback period
- Determine effects on LEED® rating of the building
- Impact on schedule

- Provide recommendation to owner on appropriateness of considering the green roof

RESOURCES AND TOOLS

- Applicable Literature
- Industry Professionals
- Course Material (AE 310, AE 404)
- Department Faculty
    - Ray Sowers
    - Kevin Parfitt
    - Moses Ling

EXPECTED OUTCOMES

Completion of Technical Analysis II is expected to show that implementation of a green roofing system above the Lecture Hall will help to significantly reduce the load of the space during the cooling season. After thorough research into various system types, a design that has minimal impact on construction cost and schedule will be considered to determine that

- the system is recommended for the project and has a favorable payback period
- the system is not recommended due to excessive cost and/or unfeasible lifecycle cost

INTRODUCTION TO GREEN ROOF SYSTEMS

The concept of a green roof originated thousands of years ago. Early humans in many areas of the world began creating shelters where plants and trees were located after realizing they helped provide warmth in the winter and cooling in the summer. More recently, sod was used to cover the roofs of homes for the same reason. Green roofs have seen a resurgence in popularity in modern times as people began realizing the increased cost of energy. Although the green roofs of today are based on this concept, technology has allowed drastically improved efficiency with the caveat of much greater expense[6].

Figure 8: An earlier green roof, common of many homes in Europe

Modern green roofs, developed in Germany in the 1960s, have long been a common feature of buildings across Europe; however, the United States has started to see an increase of adoption due to the "green" revolution sweeping the country.

There are two main types of green roofs to choose from when considering a system for a building, intensive and extensive. Intensive green roofs are often accessible to building occupants and can be thought of as rooftop gardens. They can support a wide variety of plants, including shrubs and small trees, sitting areas, and patios. The larger plants require a deep soil usually 8-12 inches, which often leads to an increased cost over simpler types of green roofs.

Extensive green roofs are usually simpler, lighter, and thinner than intensive roofs. They usually have 3-6 inches of soil that can sustain low growing plants. Extensive green roofs are almost always less expensive than intensive green roofs, and provide a better return on investment. Due to the inaccessibility of the proposed green roof, an extensive style green roof will be considered for the Gambet Center.

Figure 9: Differences between Intensive (left) and Extensive (right) styles of green roofs.

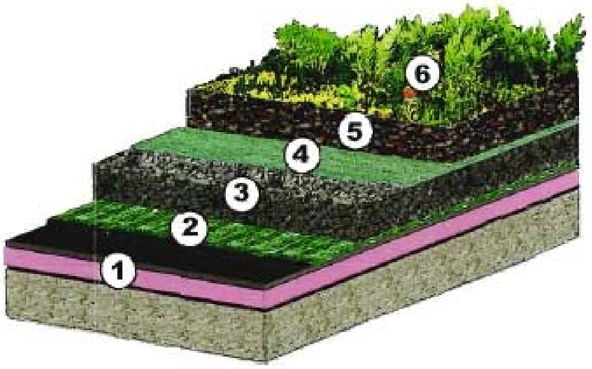
Incorporating green roofs into buildings offer many benefits to owners, occupants, and the environment. It is estimated that up to 10 trillion gallons of untreated runoff flow into waterways each year in the US. A 4-inch green roof can capture 50 percent of runoff, and are great for providing stormwater management. This leads to less runoff pollution to nearby waterways, and also helps mitigate increased water temperature in the summer, which can be harmful to wildlife. Although not as crucial in rural areas, green roofs help to curb the heat island effect and provide the site with a more constant temperature. They also offer a wildlife habitat; however, there is not a lot of data available and only anecdotal evidence shows that insects and birds are attracted to green roofs.

Owners see many benefits to green roofs, despite being considerably more expensive to construct. Traditional built-up roofs usually need to be replaced every 15-20 years due to intense direct sunlight deteriorating the waterproofing. A green roof helps protect the waterproofing membrane, and can easily double the life expectancy of the roof. Lower energy costs are also the result of choosing a green roof system over traditional construction methods. Green roofs are great insulators because they act as a thermal mass, which stores and releases heat energy without transferring it through the roof into the building. Early research shows that due to this phenomenon, green roofs save most energy in summer, leading to significant reduction to cooling costs. The energy reduction greatly varies with climate, size, and roof to wall ratio (higher is better). Owner's also see additional value through the ability to market their building as environmentally and occupant friendly. A 2008 post occupancy survey evaluation conducted by the US General Services Administration found that green building occupants were 27 percent more satisfied than the average of all US commercial buildings. Buildings rated LEED® Gold had 34% of occupants more satisfied

The main disadvantage of implementing green roofs is the considerably increased cost for both design and installation. On existing projects, the greatly increased structural load can also impose large costs. 3-4 inch green roofs typically way between 20-30 pounds per square foot. The upfront cost is offset by the longer lifespan, reduction in engineering costs for stormwater detention systems, energy savings, and incentives. In many cases, a green roof can pay for itself when considering the lifecycle cost of the system[15].

ANATOMY OF A GREEN ROOF

While many variations of green roofs exist, they are all basically comprised of the same components. Similar to built-up roofs, the bottom layer of the system consists of the roof decking, insulation, and waterproofing followed by a layer of protection. A drainage layer that allows excess moisture to easily flow to roof drains is next. A root permeable membrane should separate this and the growing medium to allow roots to grow through without letting the soil clog the drainage layer. Lastly comes the growing medium which supports the final layer of vegetation. Figure 10, below, gives a visual representation of a typical green roof system.



Each layer of a green roof assembly contributes to its function.

1 Roof deck, insulation, waterproofing
2 Protection and storage layer
3 Drainage layer
4 Root-permeable filter layer
5 Extensive growing media
6 Plants, vegetation

Illustration by Green Roof Service LLC

Figure 10: Typical Green Roof Construction

It is imperative that the correct growing medium be used when constructing a green roof. It is not simply made of typical soil, and is usually a courser mixture with a rocky look and feel. This is imperative to maintain a manageable dead load and allow water to flow freely. Silts, clays, and organic matter should be limited as their small particle size inhibit drainage, and organic matter decomposes quickly. A range of grain size distribution is provided in Table 3 below for an acceptable growing medium.

SIEVE SIZE	PERCENT PASSING
3/8”	75-100%
1/8”	30-80%
#18	5-50%
#60	‹10%
#200	‹5%
Pan	‹2%

Table 3: Acceptable Growing Medium Particle Size Distribution

Proving a good growing medium is one of the most important considerations when implementing a green roof. Plants must be able to bind to the growing medium, and remain planted in winter. Plants must also be able to survive dry periods. Maintaining a healthy layer of vegetation allows the growing medium to remain shaded, which prevents weed growth. Equally important to the growing medium, is the choice of vegetation. For extensive green roofs, low growing, long life plants should be selected. A few examples, which are pictured in Figure 11, are Sedum, Sempervivum, Talinum, Javibara, Delosperma, and Opuntia (cacti).

Figure 11: Suitable Vegetation for Extensive Green Roofs

PROPOSED GREEN ROOF DESIGN

The proposed design of the green roof considered for the Gambet Center is located on the roof of the Lecture Hall, which is part of an alternate design that was added to the scope of the project. Research on the various green roof systems provided insight into the selection of an appropriate system for this project. Due to the relatively small area and inaccessibility of the proposed location, ease of construction, and cost considerations, an extensive green roof was selected for implementation. Referencing Figure 12, one can see how the green roof system will utilize the Lecture Hall roof. The proposed design will be approximately 5585 square feet.

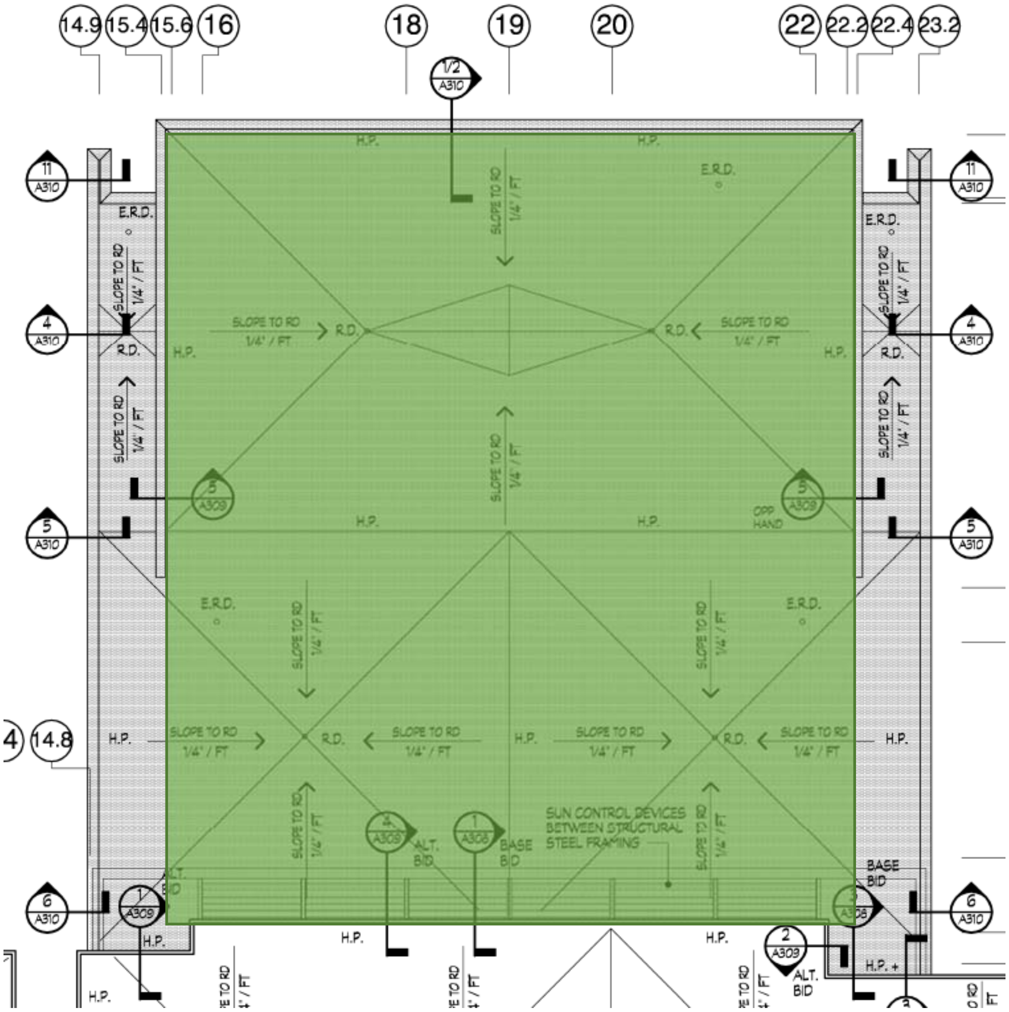


Figure 12: Proposed Green Roof Location and Size (5585 sq. ft.)

MODULAR HYBRID SYSTEM SELECTION

The selection of an actual system was the next step in the design process, and it became clear there were two options to choose from: a complete original design for the system from scratch or a pre-manufactured modular system. Due to the specification data available and easier construction, the LiveRoof® and GroRoof™ modular hybrid green roof systems were compared. Both systems are marketed as modular units that interlock to provide seamless vegetation, and can be installed directly on top of the waterproofing membrane of the existing built-up roof. The 4 ½" options of both systems will be compared due to the moderate Pennsylvania climate where 4"-6" green roofs are optimal. This also has the advantage of a substantially lower structural load.

The major differences in the components of the two systems are how they deal with drainage. The LiveRoof® system is made up of an impermeable pan with a layer of soil (2 ½"-8") and pre-established vegetation. The waffle shape of this pan is said to help the plants bind to the soil and hold the modules in place. The GroRoof™ is unique in that its modules provide built-in air circulation and drainage channels and a water retention and aeration layer that helps stabilize the roots of the vegetation. While researching green roofs, the importance of proper drainage was made clear, which makes the GroRoof™ seem that is the better system to choose. After contacting both manufacturers, the GroRoof™ was shown to have better thermal performance at a lower cost per square foot. Considering these aspects, the GroRoof™ was selected. Table 4 below summarizes the differences in the two systems and Figures 13 and 14 provide visual representation of the modular systems.

	LiveRoof ®	GroRoof™
Seamless Integration	Yes	Yes
Dedicated Drainage Channels	No	Yes
Instant Vegetation	No	Yes
R-Value	2	3
Cost per Square Foot	$24	$19
Soil Thickness	4 ½"	4 ½"
Saturated Weight per Square Foot	29	32

Table 4: LiveRoof® vs. GroRoof™ Modular Green Roof Comparison

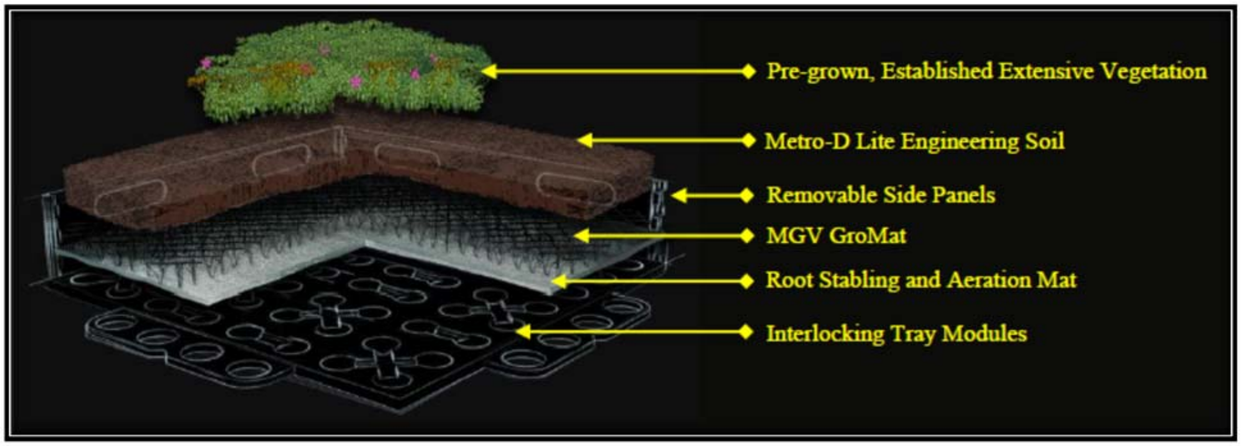


Figure 13: GroRoof™ System Components[5]

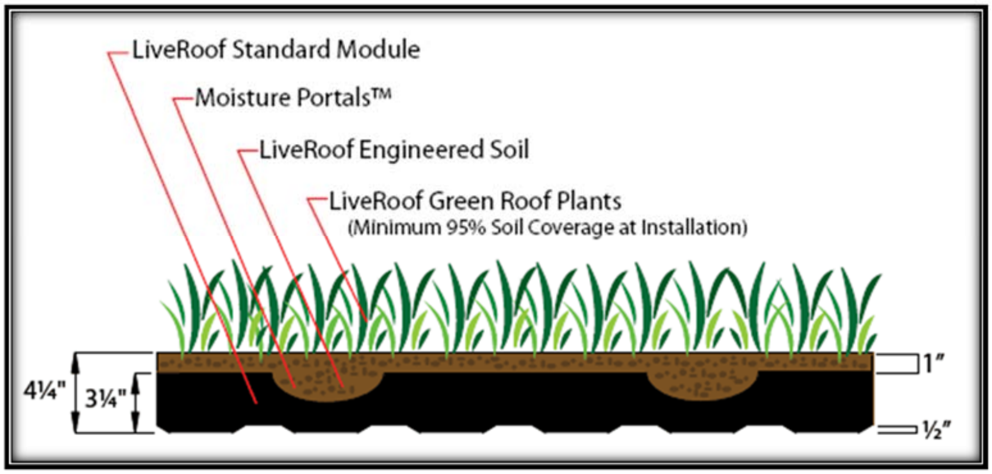


Figure 14: LiveRoof® System Components[II]

STRUCTURAL BREADTH

As currently designed, the roof of the Lecture Hall consists of tapered rigid insulation averaging a depth of 5" on 1 ½" metal roof decking topped with ½" insulation board and a single ply asphalt waterproofing membrane. The structural steel frame of the Lecture Hall must be analyzed to ensure it is able to withstand the added load of the green roof. Therefore a structural analysis will be conducted to satisfy the breadth requirement to determine if a redesign of the structural system is necessary to incorporate the green roof. Table 5 compares the difference in loading for the two roofing systems.

Item	Built-Up Roof	GroRoof™ Extensive II Modules
Steel Beam Self Weight	5 psf	5 psf
Metal Deck	2 psf	2 psf
5" Rigid Insulation	2 psf	2 psf
Mechanical, Electrical, Fire Protection	15 psf	15 psf
Ceiling	2 psf	2 psf
4 ½" GroRoof™	-	32 psf
Total Dead Load	**26 psf**	**58 psf**
Total Roof Live Load	**20 psf**	**20 psf**
Total Snow Load	**30 psf**	**30 psf**

Table 5: Dead and Live Loading of Built-Up Roof and GroRoof™

For the Extensive II system, the total dead load of the structure is 58 pounds per square foot. The roof live load and snow load were taken from the general notes of the structural plans (S208). Next, a typical bay for the roof structure was selected and the structural analysis on the beams and girders was conducted using methods taught during Architectural Engineering 404: Building Structural Systems in Steel and Concrete.

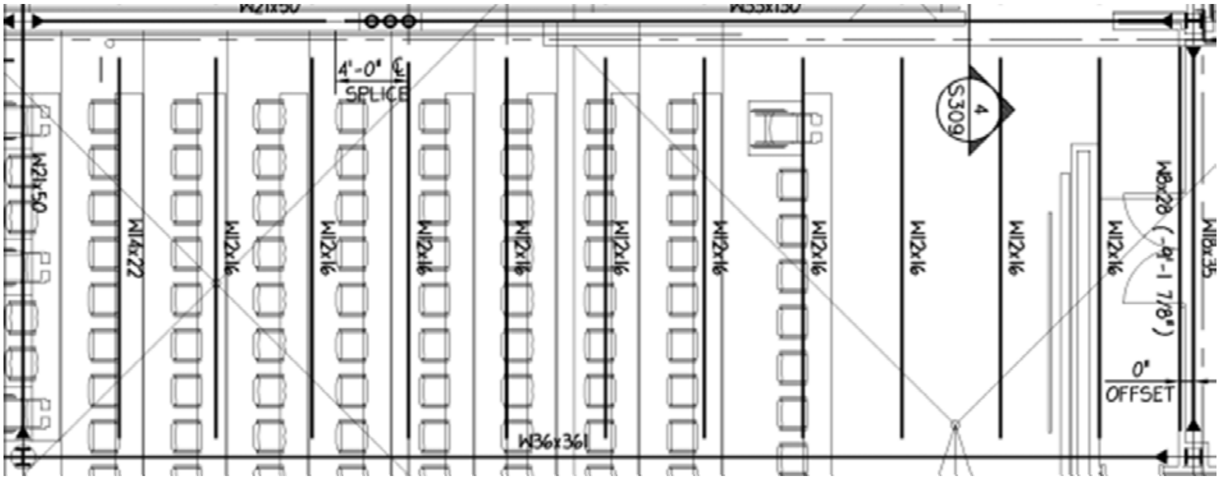


Figure 15: Typical Structural Bay Used for Analysis

As shown in Figure 15, the typical bay consists of:

- Girders:
  - (1) - 63'-9" W33x130
  - (1) - 63'-9" W36x361

- Beams: spaced 5'-4" on center
  - (10) 23'-10" W12x16
  - (1) 23'-10" W14x22
  - (1) 23'-10" W18x35
  - (1) 23'-10" W21x50

Beam Calculations

- Factored Distributed Load:
  - W=(1.2)(D)+(1.6)(L_r)+(0.5)(S) and w_u=(W)(Tributary Width)
    - W=(1.2)(58 psf)+(1.6)(20 psf)+(0.5)(30 psf) = **117 psf**
    - w_u = (117 psf)(5.33 ft) = **0.624 kips/ft**
- Factored Bending Moment:
  - Beam Fixed at Both Ends, Uniform Load: Maximum Moment at Ends
  - $M_{max} = \frac{(w_u)(l^2)}{12}$
    - $M_{max} = \frac{\left[\left(0.624\frac{k}{ft}\right)(23.833^2\ ft)\right]}{12} = 29.54$ k-ft
  - Simply Supported Beam, Uniform Load: Maximum Moment at Center
  - $M_{max} = \frac{(w_u)(l^2)}{8}$
    - $M_{max} = \frac{\left[\left(0.624\frac{k}{ft}\right)(23.833^2\ ft)\right]}{8} = 44.3$ k-ft
- Factored Shear
  - $V_u = \frac{(w_u)(l)}{2}$
    - $V_u = \frac{(.624\ k/ft)(23.883\ ft)}{2}$ = 7.44 kips

Girder Calculations

- Live Load Reduction: $L_r = L_o[.25 + \frac{15}{\sqrt{K_{LL}A_t}}]$
  - K_{LL} = 2 for girders, A_t = 1517.4
  - $L_r = 20\ psf[.25 + \frac{15}{\sqrt{(2)(1517.4)}}]$ = **10.45 psf**
- Factored Distributed Load

- $W=(1.2)(D)+(1.6)(L_r)+(0.5)(S)$ and $w_u=(W)(\text{Tributary Width})$
  - $W=(1.2)(58\text{ psf})+(1.6)(10.45\text{ psf})+(0.5)(30\text{ psf})$ = **102 psf**
- Figure 16 depicts the estimation of the multiple beam point loads as a uniformly distributed load, with shear and moment diagrams of the girders

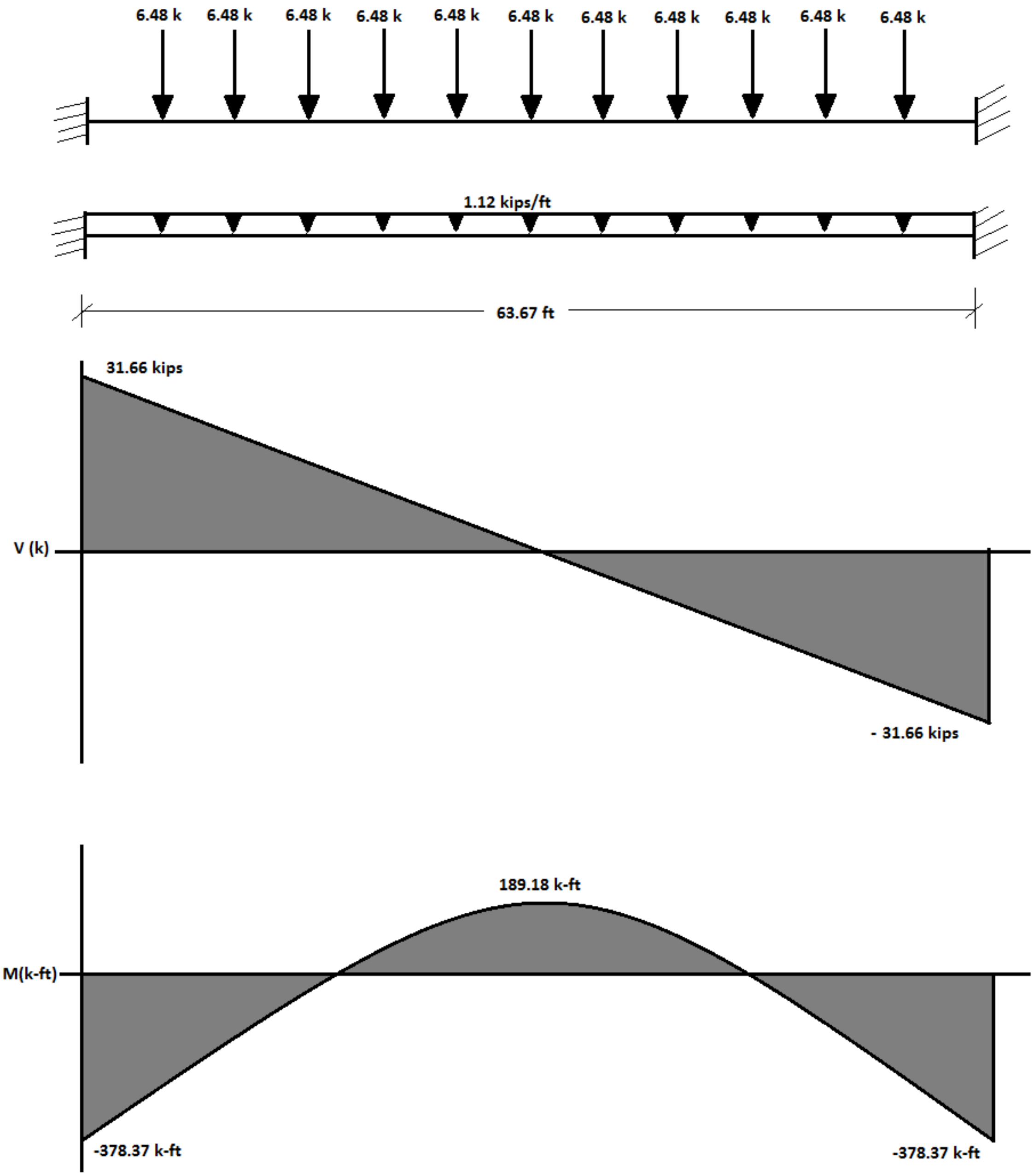


Figure 16: Girder Factored Shear and Moment Diagrams

- Beam Point Loads:

- $P_L = \frac{W \times Tributary\ Width \times Tributary\ Width}{1000}$
    - $P_L = \frac{102\ psf \times 5.33\ ft \times 11.92\ ft}{1000} =$ 6.48 kips

- Estimated Uniformly Distributed Load
    - $w = \frac{6.48\ kips \times 11\ point\ loads}{63.67\ ft} =$ 1.12 kips/ft

- Factored Shear
    - $V_u = \frac{(w_u)(l)}{2}$
        - $V_u = \frac{(1.12\ k/ft)(63.67\ ft)}{2} =$ 31.66 kips

- Factored Bending Moment
    - Beam Fixed at Both Ends, Uniform Load: Maximum Moment at Ends
    - $M_{max} = \frac{(w_u)(l^2)}{12}$
        - $M_{max} = \frac{\left[\left(1.12\frac{k}{ft}\right)(\ 63.67\ ft^2)\right]}{12} = 378.37$ k-ft
    - Moment at Center
    - $M = \frac{(w_u)(l^2)}{24}$
        - $M = \frac{\left[\left(1.12\frac{k}{ft}\right)(63.67\ ft^2)\right]}{24} = 189.18$ k-ft

Design Comparison

The strength of the steel members can be found using the ASCE Flexural Design Tables for the beams and girders used in the Lecture Hall. These values can then be compared to the results of the loading calculations above to determine if it is necessary to modify the structure. It is important to note that the loading on the center W36x361 girder will be double that of the above calculation because it is supporting twice the load the W33x130 girder on the perimeter. Table 6 below summarizes the results of these comparisons.

	Shear	Max. Shear	Moment	Max. Moment	Pass/Fail
Beams					
W12x16	7.44 k	79.2 k	44.3 k-ft	75.4 k-ft	Pass
W14x22	7.44 k	94.9 k	44.3 k-ft	125 k-ft	Pass
W18x35	7.44 k	159 k	29.45 k-ft	249 k-ft	Pass
W21x50	7.44 k	237 k	29.45 k-ft	413 k-ft	Pass
Girders					
W33x130	31.66 k	576 k	378.37 k-ft	1750 k-ft	Pass
W36x361	63.32 k	1280 k	756.74 k-ft	5810 k-ft	Pass

Table 6: Maximum Allowable Shear and Bending Moment

After completion of the prior structural calculations, it is determined that the current design of the structural system of the lecture hall is more than capable of handling the increased load of the GroRoof™ modular green roof.

MECHANICAL BREADTH

The benefit of reduced energy usage provided by the addition of the green roof above the Lecture Hall has considerable implications on the annual energy cost. This study will be used to demonstrate breadth knowledge with a mechanical analysis to compare the currently designed roof to the modular GroRoof™ system. Stated above, green roofs work especially well during the cooling season because of their ability to store heat energy from the sun during the day without transferring it into the space and then releasing it overnight. In the moderate climate of Center Valley, PA, it can be assumed that 60 percent of the cooling load coming from solar heat gain on the original built-up roof will be absorbed by the GroRoof™ Extensive II system. The mechanical breadth will use information taught during Architectural Engineering 310: HVAC Fundamentals. The Cooling Load Temperature Difference (CLTD) for solar heat gain from Chapter 28 of the 1997 ASHRAE Fundamentals Handbook will be used to quantify the total cooling load using the equation:

$$\boldsymbol{q = (U)(A)(CLTD)} \quad \text{where,}$$

q = solar heat gain (BTU/hr)

U = design heat transfer coefficient (BTU/ft^2-hr-°F)

A = area of green roof (ft^2)

CLTD = cooling load temperature difference (°F)

The area of the green roof was already found to be 5585 square feet. The U-value of the roof can be calculated by finding the inverse of the sum of each layer of the roof's R-value, which is shown in Table 7.

Roofing System Component	R-Value
1 ½" Metal Roof Decking	-
5" Rigid Insulation	20
½" Insulation Cover Board	.85
Single-Ply Asphalt Waterproofing Membrane	.15
GroRoof™ Extensive II	3
Total R-Value (ΣR)	**24**
U-Value (1/ΣR)	**.0417**

Table 7: Green Roof U-Value Calculation

The CLTD during each hour of the day is tabulated in Table 28.30 in the 1997 ASHRAE Fundamentals Handbook for various roof constructions. Table 28.31 (shown below in Figure 17a) is used to determine the Roof Number to be used in Table 28.30 (shown in Figure 17b).

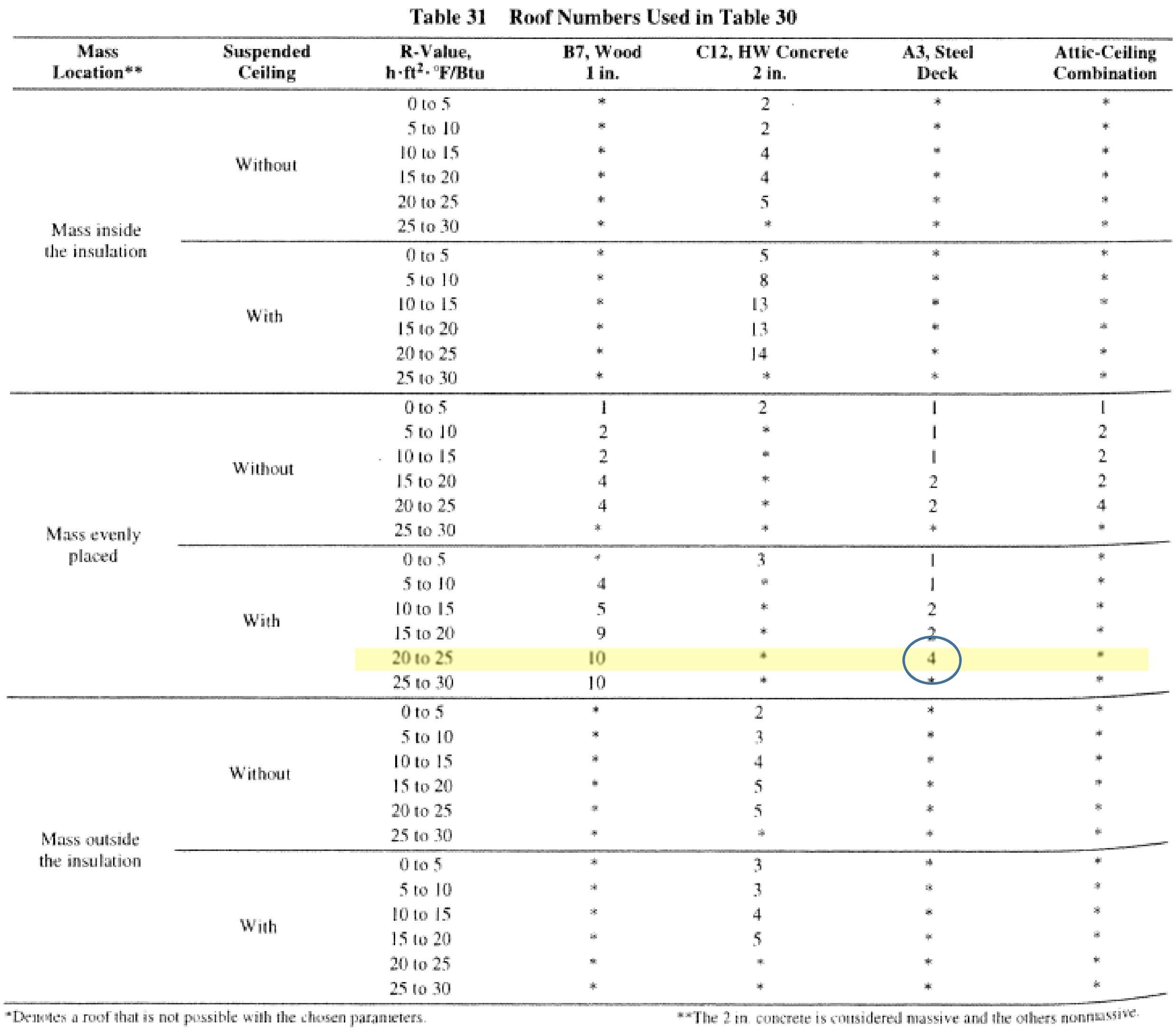


Table 31 Roof Numbers Used in Table 30

Mass Location**	Suspended Ceiling	R-Value, h·ft²·°F/Btu	B7, Wood 1 in.	C12, HW Concrete 2 in.	A3, Steel Deck	Attic-Ceiling Combination
Mass inside the insulation	Without	0 to 5	*	2	*	*
		5 to 10	*	2	*	*
		10 to 15	*	4	*	*
		15 to 20	*	4	*	*
		20 to 25	*	5	*	*
		25 to 30	*	*	*	*
	With	0 to 5	*	5	*	*
		5 to 10	*	8	*	*
		10 to 15	*	13	*	*
		15 to 20	*	13	*	*
		20 to 25	*	14	*	*
		25 to 30	*	*	*	*
Mass evenly placed	Without	0 to 5	1	2	1	1
		5 to 10	2	*	1	2
		10 to 15	2	*	1	2
		15 to 20	4	*	2	2
		20 to 25	4	*	2	4
		25 to 30	*	*	*	*
	With	0 to 5	*	3	1	*
		5 to 10	4	*	1	*
		10 to 15	5	*	2	*
		15 to 20	9	*	2	*
		20 to 25	10	*	4	*
		25 to 30	10	*	*	*
Mass outside the insulation	Without	0 to 5	*	2	*	*
		5 to 10	*	3	*	*
		10 to 15	*	4	*	*
		15 to 20	*	5	*	*
		20 to 25	*	5	*	*
		25 to 30	*	*	*	*
	With	0 to 5	*	3	*	*
		5 to 10	*	3	*	*
		10 to 15	*	4	*	*
		15 to 20	*	5	*	*
		20 to 25	*	*	*	*
		25 to 30	*	*	*	*

*Denotes a roof that is not possible with the chosen parameters.

**The 2 in. concrete is considered massive and the others nonmassive.

Figure 17a: ASHRAE Table 28.31 Used to Determine Roof Number of Roof Construction Type[2]

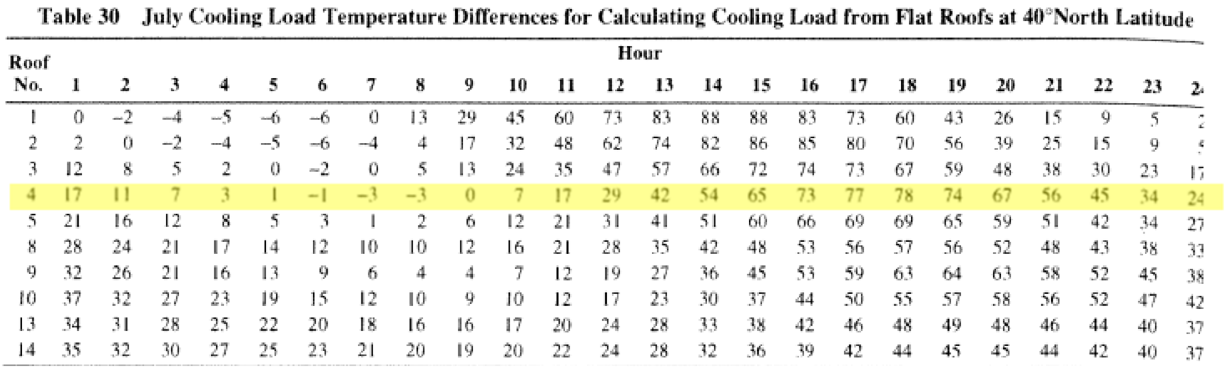


Table 30 July Cooling Load Temperature Differences for Calculating Cooling Load from Flat Roofs at 40°North Latitude

Roof No.	Hour 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
1	0	−2	−4	−5	−6	−6	0	13	29	45	60	73	83	88	88	83	73	60	43	26	15	9	5	[illegible]
2	2	0	−2	−4	−5	−6	−4	4	17	32	48	62	74	82	86	85	80	70	56	39	25	15	9	[illegible]
3	12	8	5	2	0	−2	0	5	13	24	35	47	57	66	72	74	73	67	59	48	38	30	23	17
4	17	11	7	3	1	−1	−3	−3	0	7	17	29	42	54	65	73	77	78	74	67	56	45	34	24
5	21	16	12	8	5	3	1	2	6	12	21	31	41	51	60	66	69	69	65	59	51	42	34	27
8	28	24	21	17	14	12	10	10	12	16	21	28	35	42	48	53	56	57	56	52	48	43	38	33
9	32	26	21	16	13	9	6	4	4	7	12	19	27	36	45	53	59	63	64	63	58	52	45	38
10	37	32	27	23	19	15	12	10	9	10	12	17	23	30	37	44	50	55	57	58	56	52	47	42
13	34	31	28	25	22	20	18	16	16	17	20	24	28	33	38	42	46	48	49	48	46	44	40	37
14	35	32	30	27	25	23	21	20	19	20	22	24	28	32	36	39	42	44	45	45	44	42	40	37

Figure 17b: ASHRAE Table 28.30 for Hourly CLTD in July for Roof No. 4[2]

Roof Number 4 from Figure 17a was chosen because it is the most similar to the roof construction of the Lecture Hall. It is important to note that this method only gives the CLTD values during the month of July at the 40° North Latitude. The CLTD values must then be corrected using the equation:

$$CLTD_{corr} = CLTD + (78 - t_r) + (t_m - 85) \quad \text{where,}$$

t_r = inside temperature (65°F), and

t_m = mean outdoor temperature (73°F)

For the following mechanical analysis, these values will be used for the entire cooling season from May 1 to September 31. Table 8 summarizes the annual reduction in cooling load for the Gambet Center's Lecture Hall with the implementation of the proposed green roof system.

HOUR	CLTD	$CLTD_{corr}$	U	A	q
1	17	18	0.0417	5855	4395
2	11	12	0.0417	5855	2930
3	7	8	0.0417	5855	1953
4	3	4	0.0417	5855	977
5	1	2	0.0417	5855	488
6	-1	0	0.0417	5855	0
7	-3	-2	0.0417	5855	-488
8	-3	-2	0.0417	5855	-488
9	0	1	0.0417	5855	244
10	7	8	0.0417	5855	1953
11	17	18	0.0417	5855	4395
12	29	30	0.0417	5855	7325
13	42	43	0.0417	5855	10499
14	54	55	0.0417	5855	13428
15	65	66	0.0417	5855	16114
16	73	74	0.0417	5855	18067
17	77	78	0.0417	5855	19044
18	78	79	0.0417	5855	19288
19	74	75	0.0417	5855	18312
20	67	68	0.0417	5855	16602
21	56	57	0.0417	5855	13917
22	45	46	0.0417	5855	11231
23	34	35	0.0417	5855	8545
24	24	25	0.0417	5855	6104
Total Daily Cooling Load in BTU					194,834
Total Annual Cooling Load in BTU (153 days)					29,809,677
Green Roof Cooling Load Reduction in BTU (60%)					**17,885,806**

Table 8: CLTD Method Calculations and Annual Reduction in Cooling Load

A reduction of 17,885,806 BTU to the cooling load of the Lecture Hall is calculated when considering the addition of the GroRoof™ Module Hybrid Green Roof System. This reduction in cooling load can be used to estimate the annual savings of cooling energy cost. The air handling units used in the Lecture Hall have an Energy Efficiency Ratio (EER) of 10.9. This is a ratio of the cooling load in BTU/hr to the applied electrical power in watts. Over the entire cooling season, a load of 17,885,806 BTU is equivalent to 4,871 BTU/hr. When given an EER of 10.9, removal of 17,885,806 BTUs requires 1,358 kWh over the cooling season of May to September. At a rate of $0.09 per kWh, the implementation of the green roof results in an annual cost savings of only $147.68. This is a lot lower than would be desired and is consequential of the high thermal resistance of the insulation, which on its own significantly reduces the solar heat gain on the building.

LIFECYCLE COST ANALYSIS

A lifecycle cost analysis of the green roof must be conducted to determine the financial feasibility of the implementation. Although the costs of green roofs can be a large financial burden to the owner, energy savings and other factors that help the owner save money over time should be considered to see how much they can outweigh the up-front cost.

Up- Front Cost Estimate

When comparing the GroRoof™ and LiveRoof® Module Hybrid Green Roof Systems, the cost of each system was a key factor in the final decision. Fortunately, at an average of $19 per square foot[21] in the Northeast region, the GroRoof™ was $5 less than the LiveRoof[20], while also containing more desirable features. An up-front cost of $111,245 for the system is calculated when applying this figure to the 5,855 square foot area of the green roof. The roof will only be accessible to maintenance employees, so there are no additional costs for pavers and outdoor furniture.

Energy Savings

Determined above in the Mechanical Breadth, a cost savings of $147.68 for the solar cooling load was estimated. This figure is low and indicates that the initial cost of the green roof will not be offset by the energy savings. Other factors such as government incentives and the longevity of the roof must also be analyzed.

Longevity Savings

Green roofs last almost twice as long as the traditional roof originally designed for the Gambet Center. Making an investment in a green roof, thus, results in a large cost savings from relieving the owner of having to replace the roof as often. Taking the bid cost for roofing and dividing by the area of the entire roof, a square foot cost of $13.27 is calculated. An estimated cost of $77,688 can then be figured for the roof of the lecture hall. Assuming the original roof would remain effective for 25 years, it would take this long for the owner to realize the savings.

Incentive Savings

There are often tax incentives given to owners through various channels of government when implementing energy reduction usage solutions to their buildings, which includes green roofs. The federal government offers the Clean Energy Stimulus & Investment Assurance Act, offers commercial property owners a tax credit for up to 30 percent of the initial cost of the system. Unfortunately, the green roof system considered in this technical analysis does not qualify because it does not cover at least half of the roof, a provision of this incentive. The green roof may, however, qualify for incentives offered by Pennsylvania.

Currently proposed to state legislation, an income tax credit for commercial green roofs in the amount of 25 percent of the original cost may be claimed for the first 6 years of the system life. If the assumption of a 30 percent tax rate is made, DeSales would save approximately $50,000 in taxes over the first 6 years[3]. This works out to 45 percent of the cost of the green roof system being offset by tax savings.

Cost Analysis

The GroRoof™ Extensive II Hybrid System is expected to have a useful life expectancy of 40 years. After 40 years, the implementation of a green roof will be satisfactory if the initial cost of the system is paid back within that timeframe, although many owners want payback periods in the range of 5 to 6 years. With the rapid change of technology and unpredictable financial markets, the effect of inflation will not be considered. Instead, it will be assumed all prices inflate at the same rate. Therefore, the total cost savings to the owner will be expressed in the value of today's dollar.

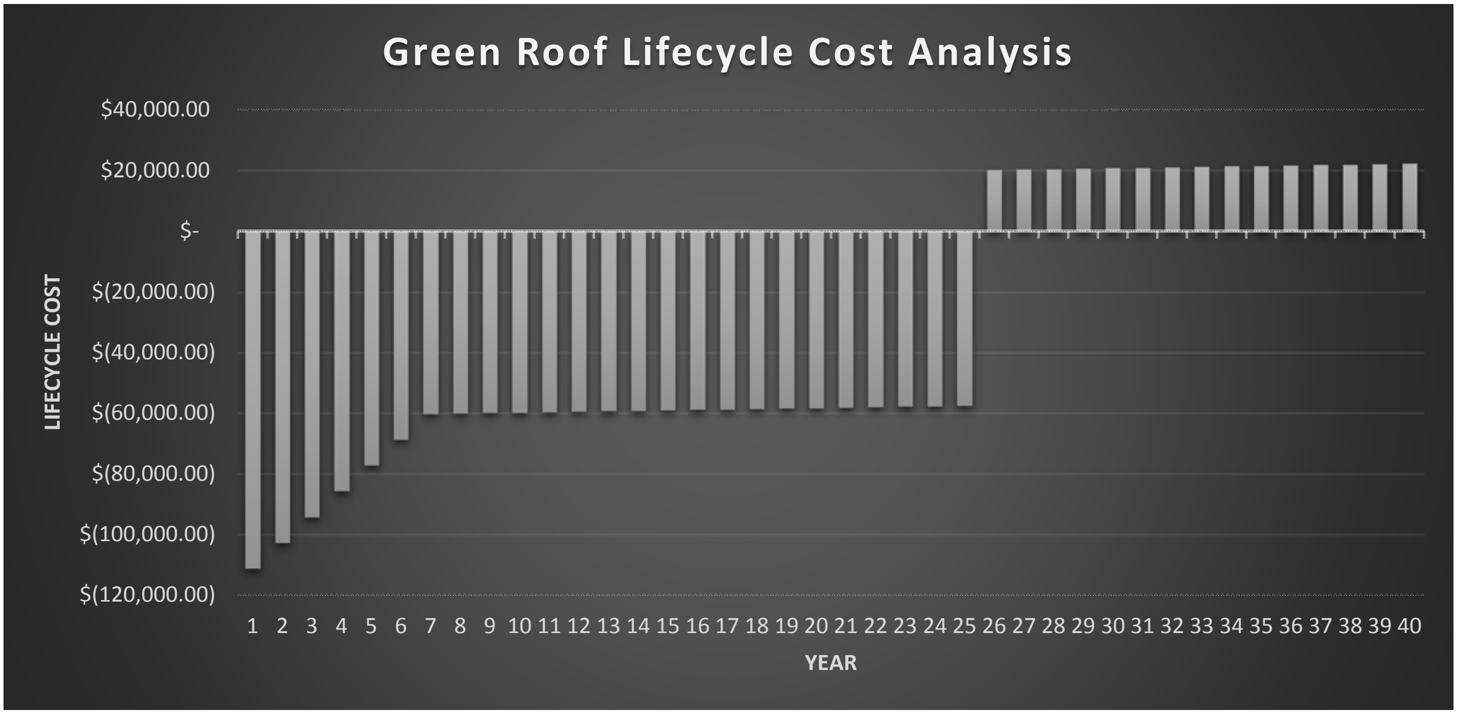


Figure 18: Lifecycle Cost Analysis of Green Roof Implementation

As the bar graph in Figure 18 shows, DeSales would not see the cost of the green roof repaid until the 25th year, which aligns with the year the owner would need to get the original roof replaced. It is easily seen in Figure 18 that the incentives during the first six years rapidly decrease the lifecycle cost of the owner. The plateaus in the graph depict the low energy savings, keeping the lifecycle cost almost constant for 19 years. This is the time when the owner would gain savings from not having to replace the original roof. At this point, the green roof has paid for itself and the owner sees total savings of $20,195. This is again followed by low energy savings growth. Ultimately, the owner would gain $22,263 in savings from deciding to implement the proposed green roof.

IMPLEMENTATION

The GroRoof™ Hybrid Green Roof Systems was specifically selected to minimize the impact on construction. The large site in rural Pennsylvania provides more than enough additional space to store the green roof modules. Although the modules come with pre-established vegetation, it would be of the construction manager's best interest to ensure the survival of the plants before installation. The roof was completed in March 2012, so the weather would most likely be satisfactory for the modules. On cold days where temperatures are expected to create frost, the modules should be covered in thermal blankets and heated if necessary.

Once delivered to the site, installation of the GroRoof™ modules goes quickly. According to the manufacturer's website, a crew of 2 can install 2,950 square feet in a single 8 hour shift. For the green roof in consideration, this would require 2 days to complete. This would not interrupt the critical path, or any other activity.

LEED® AND FINAL RECOMMENDATION

The Gambet Center was purposefully designed to be very energy conscious, and this is made clear when reflecting on the energy savings of implementing a green roof solution above the Lecture Hall. A savings of $147.68 is really negligible in terms of the total annual heating and cooling cost for the building. With the Gambet Center expected to gain 4 out of 19 LEED® credits for Optimizing Energy Performance by 18 percent, the addition of the green roof will not make a large enough impact to increase the energy performance to 20 percent. The 1,358 kWh saved through the addition of the green roof is equivalent to less than two tenths of a percent increase in efficiency for the entire building.

Although the system will pay for itself within its lifespan, the dismal energy savings slow the payback period to 25 years. This is an unfavorable condition for DeSales University, who likes to see most of their green efforts pay for themselves within 5 to 10 years. With the ultimate goal of the technical analyses to help the building achieve a LEED® Gold rating, it is not recommended to implement a green roof above the Lecture Hall.

TECHNICAL ANALYSIS III: ON-SITE RENEWABLE ENERGY

PROBLEM IDENTIFICATION

DeSales University has made major strides with incorporating sustainable practices into their campus operations, most notably in the construction of their new buildings. The McShea Student Center was the first LEED® Accredited building on the campus, and is followed by the Gambet Center. Rewarded for leadership in sustainability, DeSales has the opportunity to take that role even further by starting to incorporate energy independence into its practices. Photovoltaic technologies can be explored to help DeSales remain a leader in the area, while also showing a strong commitment to sustainability that most owners do not pursue.

RESEARCH GOALS

The goal of Technical Analysis III will be to study photovoltaic systems for implementation on the roof of the Gambet Center. A financially feasible system will be designed in an effort to provide a substantial amount of the building's energy through renewable energy generated on site. After the LEED® Evaluation detailed in the Project Overview section of this report, 7 of the 10 points needed for a Gold rating can be achieved through using renewable energy. Considering the difficulty and high cost of improving the energy efficiency of buildings, it is crucial the photovoltaic array qualify for all 7 points available for on-site renewable energy implementations and produce at least 13 percent of the building's energy in order to have a chance of reaching LEED® Gold.

METHODOLOGY

- Research photovoltaic systems suitable for the Gambet Center and their connection into the building
- Conduct a solar study to analyze optimal array position on the roof
- Calculate the total energy produced by the solar panel arrays
- Investigate alternative applications of on-site renewable energy
- Determine lifecycle cost and payback period of proposed system
- Compare the total building electricity usage to the generation capacity of the PV system
- Make final recommendation on including a PV system

RESOURCES AND TOOLS

- Applicable Literature
- Project Vasari Conceptual Energy Modeling Software
- NREL PVWatts™ Photovoltaic Calculator
- Industry Professionals
- Department Faculty

EXPECTED OUTCOME

The inclusion of a PV array is expected to be a viable application to reduce electricity consumption and help toward gaining a higher LEED® rating. It is believed that the lifecycle analysis will show that the system will pay for itself within the standard 25 year lifecycle of photovoltaic arrays. Covering the roof alone is not expected to provide the electric generation required to meet these goals. Therefore, it will most likely be necessary for supplemental implementations of renewable energy, such as wind turbines or PV structures in the parking lot, to be investigated.

INTRODUCTION TO SOLAR ENERGY AND PHOTOVOLTAIC SYSTEMS

The amount of energy needed to sustain the global population for an entire year comes from the sun in just one hour. Although this abundance of energy is available at any time, mankind has only started to develop a way to capture and convert this energy very efficiently. Solar energy arrives to Earth in the forms of heat and light. The heat energy can be collected and used to heat water or air for commercial and residential use. It can also be used with steam and sterling engines to generate electricity or perform mechanical work.

Another way the sun's energy reaches Earth, and what this technical analysis will focus on, comes in the form of light. Through the use of photovoltaic technology, this light energy can be converted to electricity. Energy that is created without depleting fossil fuels or nuclear energy is defined as renewable energy. In terms of all energy generation on the planet, 78 percent is currently sourced through depleting fossil fuels (74%) and nuclear energy (4%). The remaining fraction (22%) is comprised of renewable energy sources. Today's sources of renewable energy are essentially from indirect uses of solar energy, such as creating winds and tides. Interestingly, 14 percent of the world's total energy generation is from biological life forms. Figure 19 details an overview of today's energy sources.

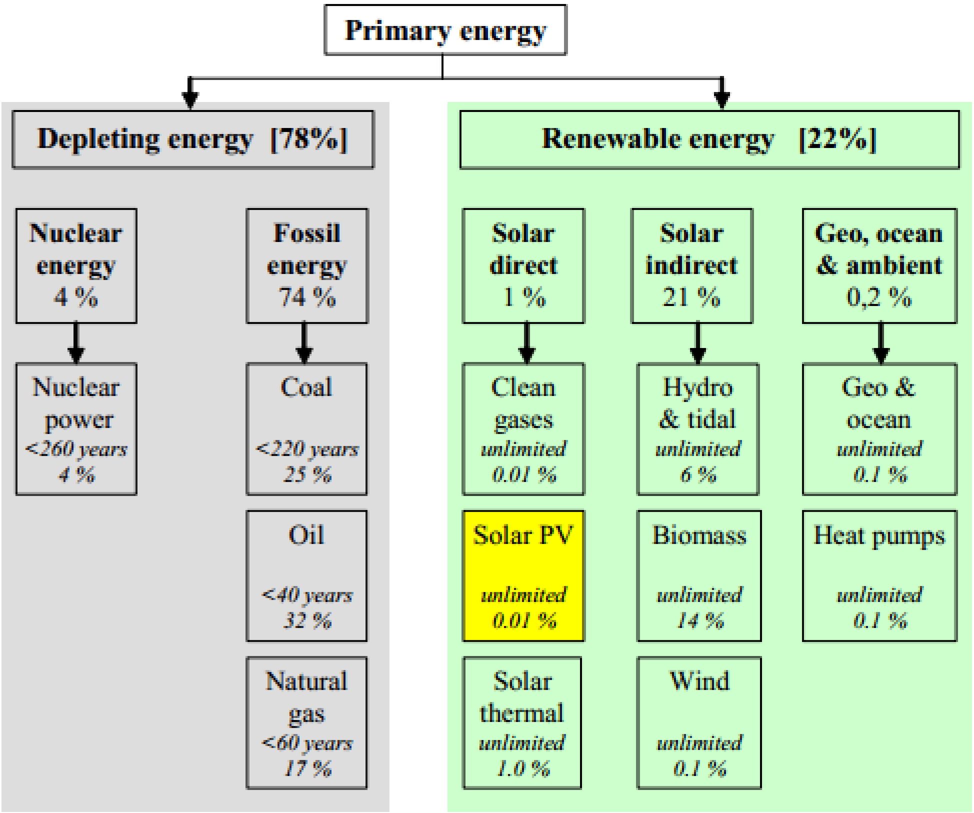


Figure 19: Current Planetary Energy Sources[22]

It can be seen in Figure 19 that photovoltaics contribute to only 0.01 percent of energy generation. This is a combination of the limited use of photovoltaic systems today and the inefficiency in converting solar power to electricity. The biggest obstacle to photovoltaic solar panels is their low efficiency and high cost per generated watt. If these issues can be solved, the technology will hopefully contribute to a larger percentage of primary energy by becoming more widely adopted.

A photovoltaic array consists of a matrix of modules that are connected together. Each module contains many solar cells that are connected to wires and responsible for converting the light energy into an electric current. Photovoltaic (PV) cells are comprised of semiconductors that are usually silicon and literally produce a voltage (voltaic) when interacting with light (photo). As light energy reaches the cell, a portion of it is absorbed into the crystalline semiconductor forcing electrons loose. These electrons flow through the cell wire, thus creating a current. The more light a cell can absorb is proportional to the amount of energy it can produce. Scientists around the world are working to discover an economically sound way to increase the solar absorption efficiency of the solar cell. It is important to remember that solar cells do not store electricity, they merely generate it. How the array(s) use or store the electricity depends on the specific PV system, and will be discussed in more detail later.

A matrix of these solar cells are assembled and placed in a frame and covered with clear glass. An encapsulant layer is often between the silicon cells and glass to help protect cells from moisture and contaminants, both of which can easily lead to failure of the cell. This assembly is what is referred to as a module, and also have a junction box that directs the electrical current of each cell to the connected load. Again, an array is made of a collection of modules that are connected.

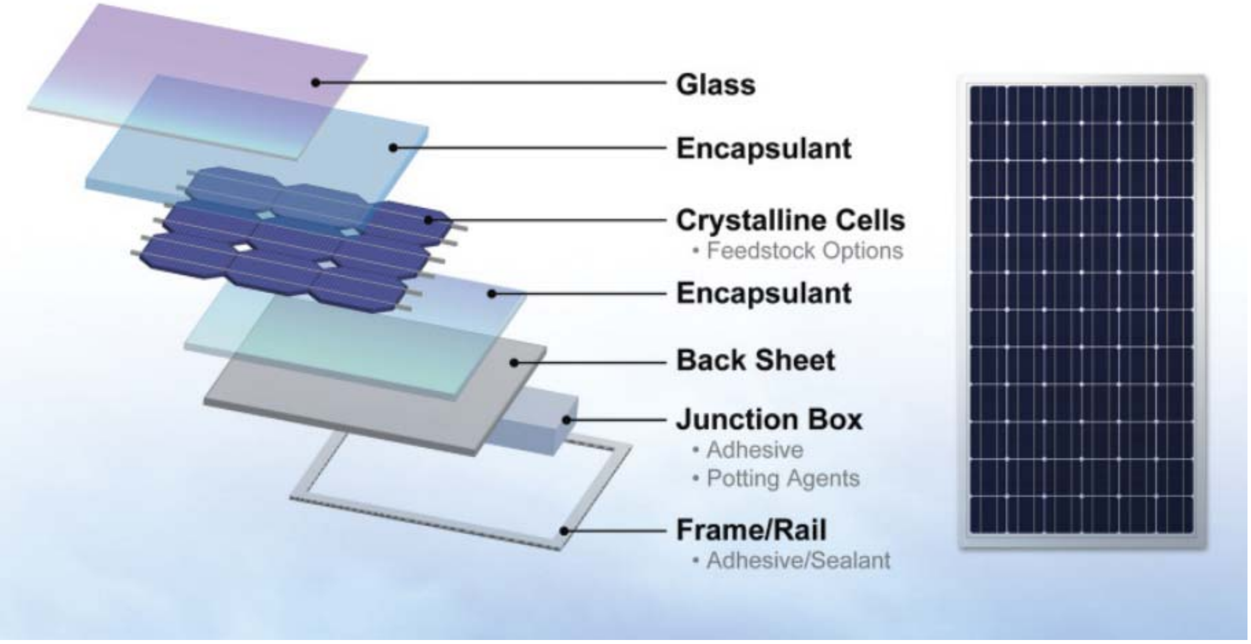


Figure 20: Solar Panel Module[16]

The electricity created by the solar cells is direct current, and not suitable for most commercial applications. It is necessary to convert the direct current (DC) to alternating current (AC), and is done through the use of an inverter. Inverters are sized based on the maximum DC power they can convert at any time. It is possible to connect a larger number of PV arrays to a higher rated inverter, but it must be ensured the rating of the inverter is greater than the power output of the connected arrays.

Once the electricity is converted to AC, it must either be used by the connected loads of the building, flow into the grid, or be stored in a battery bank. The first option allows the loads to utilize the solar generated electricity, but also has the potential to waste unused electricity in the event the system is creating more electricity than is being used. The two remaining options are classified as grid tie-in systems or battery storage systems. Systems that tie into the electrical grid are able to use the electricity available when needed, while saving the wasted energy by selling it back to the utility. A battery storage system is when the electricity from the array is used to charge batteries that store the generated electricity for future/present use. When the electricity is needed, it is taken from the battery and goes through the inverter before being used by the building. These systems may or may not be supplemented by utility power; however, the solar power does not interact with the grid. While this has the benefit of being a completely stand-alone system, the advantage is heavily outweighed. The additional cost of the battery bank is a substantial portion of the system cost, and they are expensive to maintain. Also, generated electricity can be wasted if the batteries reach their maximum charges. For these reasons, a grid tie-in system will be chosen for the Gambet Center. A one-line diagram comparing these two types of systems are shown below in Figure 21.

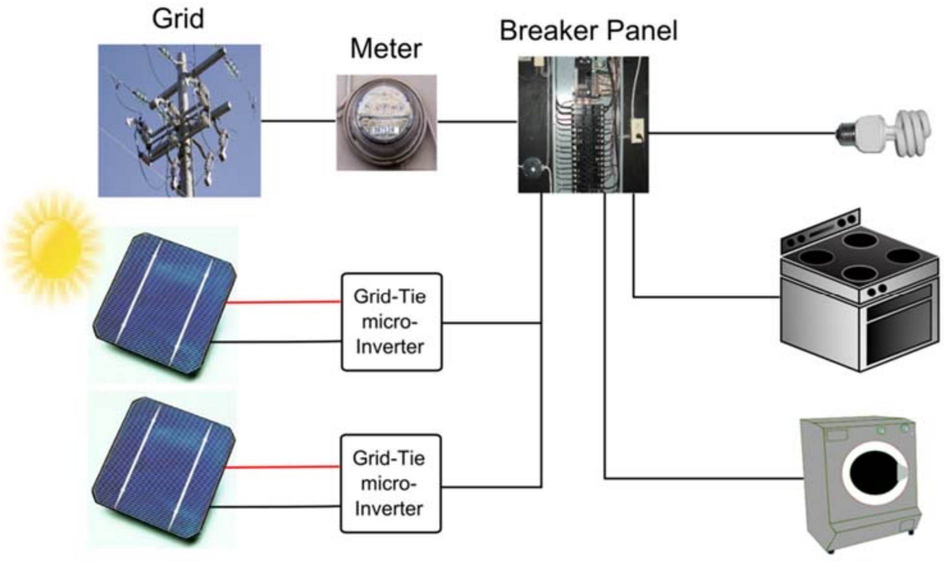


Figure 21a: Grid Tie-In Photovoltaic System

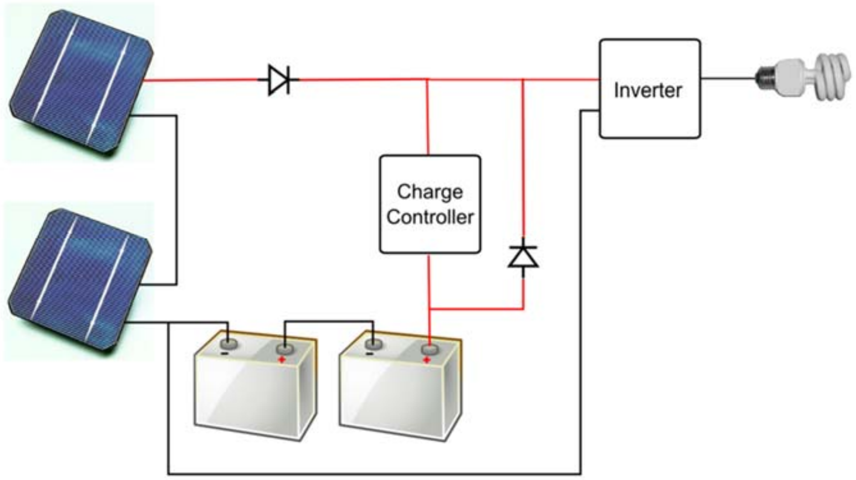


Figure 21b: Battery Storage Photovoltaic System

PHOTOVOLTAIC ARRAY DESIGN

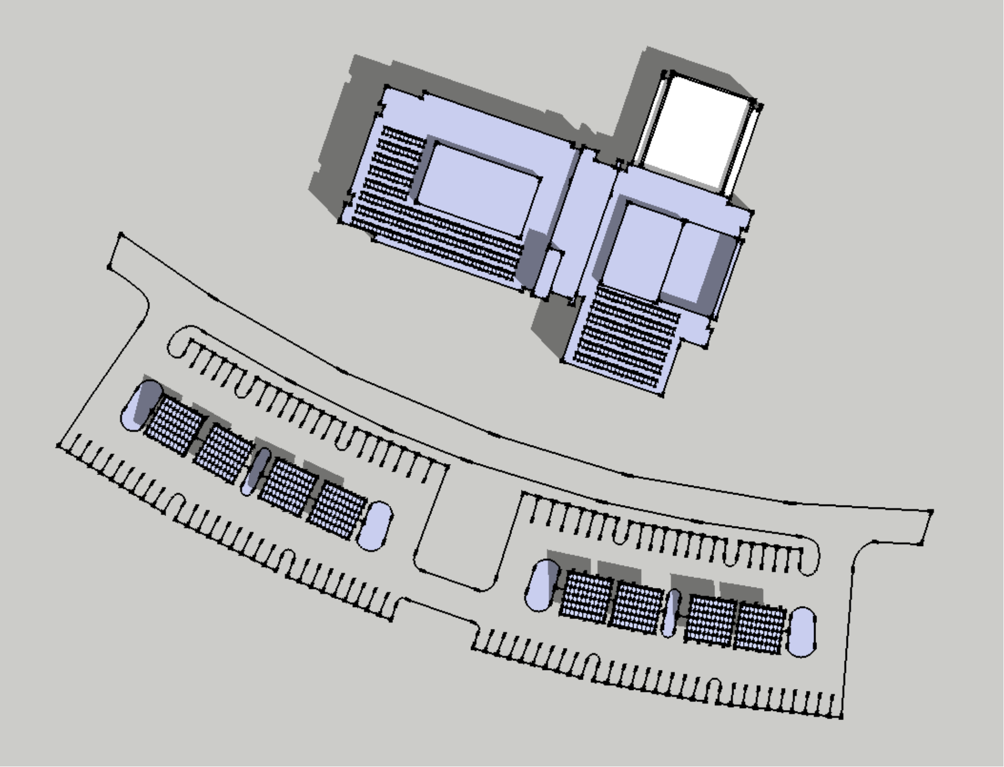
Before the design of the PV array can begin, it is necessary to understand the site, building orientation, and solar radiation at various times of the day. The solar study is also important to determine the optimal tilt angle of the solar panels when calculating the necessary spacing between the arrays to prevent shading on the solar cells. The design of the proposed PV array will utilize a 250 watt Astroenergy NOVA series monocrystalline photovoltaic module, detailed in Appendix D-1. This is a fairly common type of panel for the industry, and was selected to perform well with the cost data used when estimating the cost of the system.

Solar Study

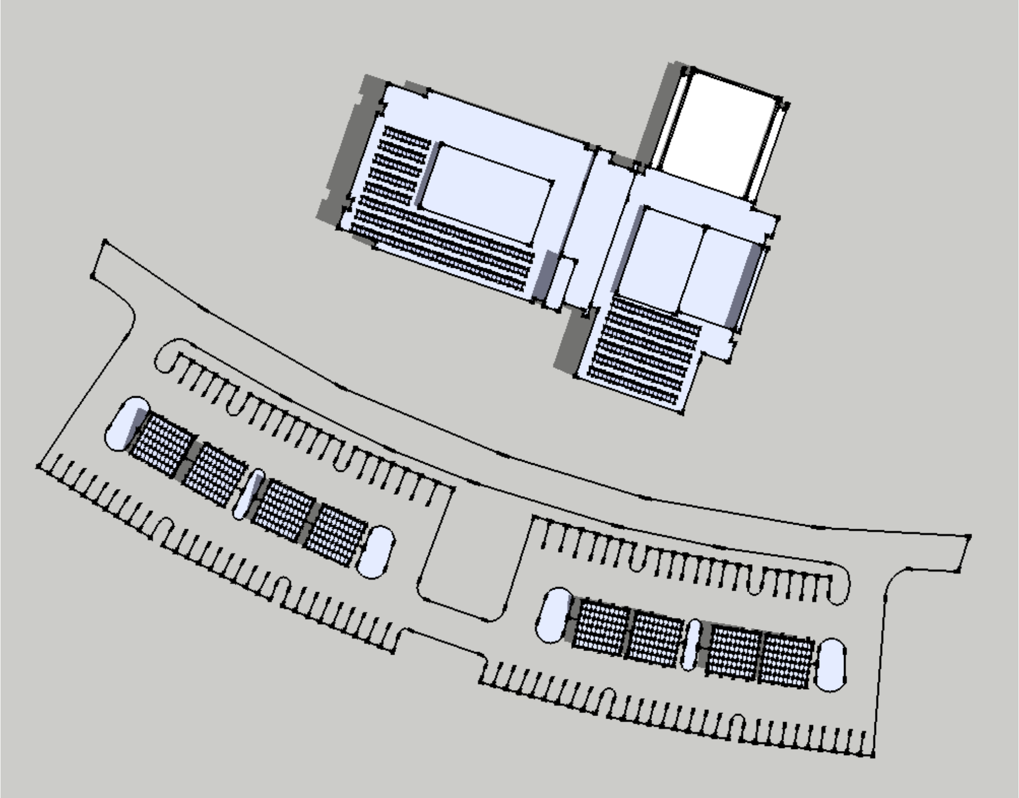
Part of the solar study involves finding the optimal row spacing between arrays needs to be calculated before the arrays can be laid out on the roof. This spacing can be formulated using an optimal fixed panel tilt of 33.5° for a North 40° Latitude[10] and the 5.42 foot solar panel height. The solar arrays will cast the largest shadow on the Winter Solstice when the solar angle is about 26°, which results in a shadow length of 6.13 feet.

Referencing the civil construction drawings, it was found that the Gambet Center is oriented 19° to the west of south. This direction is advantageous because a building that faces mostly south is highly efficient at receiving direct sunlight. Creating a mass model of the Gambet Center in

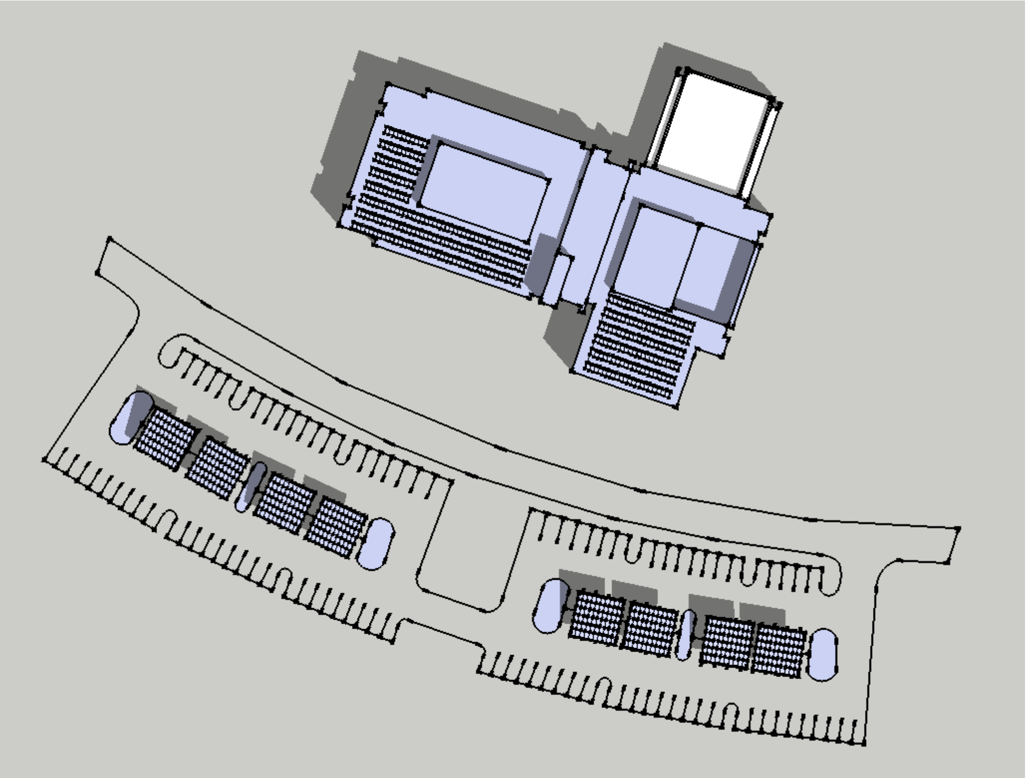
Trimble SketchUp and using the built in sun shadow tools allows a comprehensive look at the solar radiation and shading on the building at different times of the year.



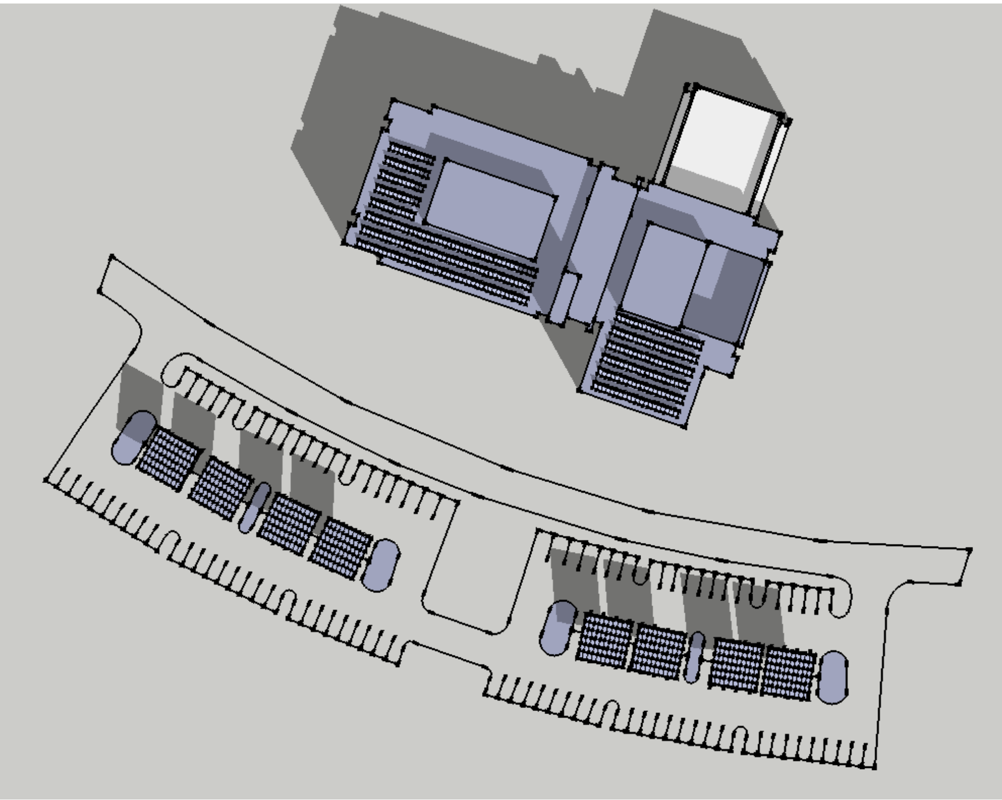
March 21 – 12:00pm



June 21 – 12:00pm



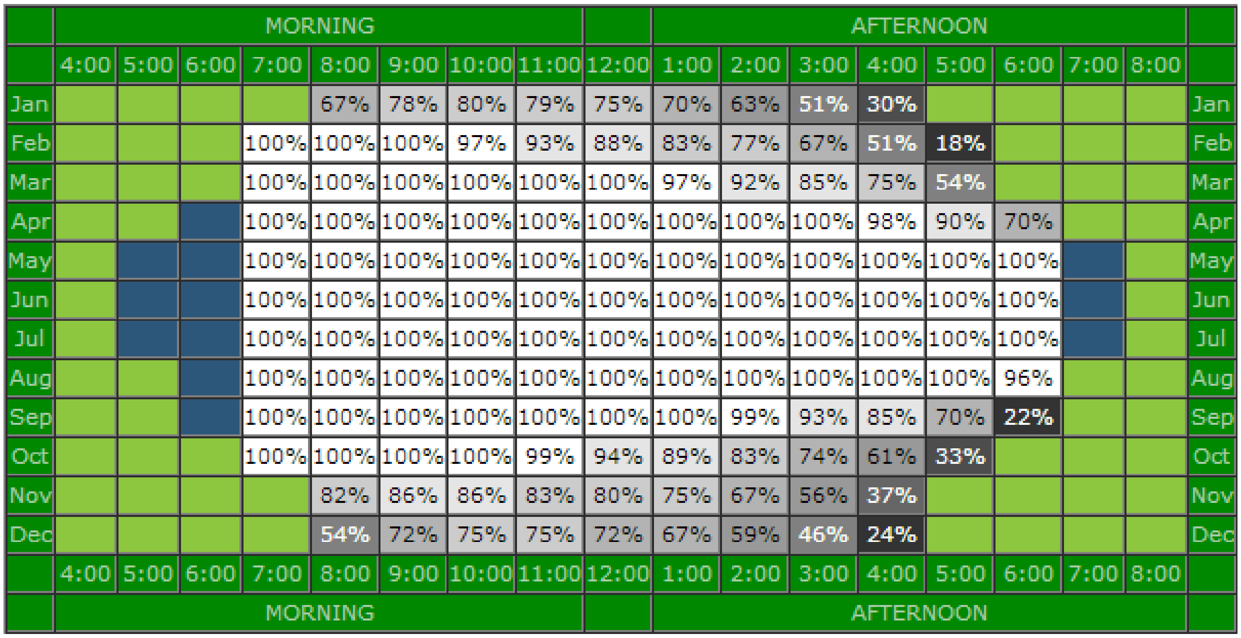
September 21 – 12:00pm



December 21 – 12:00pm

Figure 22: Solstice and Equinox Sun Shadows at Noon

Figure 22 gives a visual idea of the how the sun will cast shadows on the building throughout the year. The roof screens concealing the rooftop air handling units cast shadows on the roof behind that make the north side of the building unsuitable for solar panels. Considering the 6.13 foot spacing between arrays, a total of 310 Astronenergy NOVA, arranged in 31 arrays of 10 modules can be placed on the roof. Entering these parameters into a panel shading calculator[4], a matrix detailing the percentage of shading on panels cast from parallel rows is generated. Figure 23 supports the photovoltaic system design by showing very minimal shading during the summer months. It also shows considerable shading during the winter months; however, these months are poor for solar collection due to the low solar angle, so it is better to optimize the system for summer.



	MORNING									AFTERNOON							
	4:00	5:00	6:00	7:00	8:00	9:00	10:00	11:00	12:00	1:00	2:00	3:00	4:00	5:00	6:00	7:00	8:00	
Jan					67%	78%	80%	79%	75%	70%	63%	51%	30%					Jan
Feb				100%	100%	100%	97%	93%	88%	83%	77%	67%	51%	18%				Feb
Mar				100%	100%	100%	100%	100%	100%	97%	92%	85%	75%	54%				Mar
Apr			🟦	100%	100%	100%	100%	100%	100%	100%	100%	100%	98%	90%	70%			Apr
May		🟦	🟦	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	🟦		May
Jun		🟦	🟦	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	🟦		Jun
Jul		🟦	🟦	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	🟦		Jul
Aug			🟦	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	96%			Aug
Sep			🟦	100%	100%	100%	100%	100%	100%	100%	99%	93%	85%	70%	22%			Sep
Oct				100%	100%	100%	100%	99%	94%	89%	83%	74%	61%	33%				Oct
Nov					82%	86%	86%	83%	80%	75%	67%	56%	37%					Nov
Dec					54%	72%	75%	75%	72%	67%	59%	46%	24%					Dec
	4:00	5:00	6:00	7:00	8:00	9:00	10:00	11:00	12:00	1:00	2:00	3:00	4:00	5:00	6:00	7:00	8:00	
	MORNING									AFTERNOON								

Figure 23: Sunlight Percentages Due to Parallel Row Shading

Parking Lot Solar "Trees"

Figure 24: Envision Solar Tree® Parking Lot Solar Arrays

The south facing parking lot also provides a great opportunity to incorporate structures holding solar cells to expand the generation capacity of the system. Envision Solar manufactures solar "tree" structures for use in parking lots which can be used as an extension to the planned PV system, or used to charge electric vehicles. Each Solar Tree® Structure produces 14.40 kilowatts of DC current. For a detailed data sheet of the Solar Tree®, please see Appendix D-2.

When referencing the civil drawings of the parking lot, it is possible for eight Solar Tree® structures to fit almost perfectly in the center parking row. The design layout of these solar panels along with the sun shadows on the site can be seen in Figure 24. The PV array layout proposed for Technical Analysis III is now complete, and consists of 310 rooftop solar panels and 8 Envision Solar Trees® for a total generation capacity of about 193 kilowatts.

Inverter Sizing

The inverters are the final components of the PV system that need to be selected for the Gambet Center. Commercial inverters come in a vast number of ratings from 10 kilowatts to 500 kilowatts. As the amount of DC that can be converted to AC at any given time increases, the cost of the inverter can get drastically more expensive. A SatCon Powergate Plus 100 kilowatt inverter, was selected for the roof array because it is cost effective while allowing the entire rooftop system to connect to a single inverter with plenty of room for expansion, if needed. A SatCon Powergate Plus 135 kilowatt inverter was similarly selected for the parking arrays. This combination of inverters has the benefit of the lowest cost for the conversion requirements of the arrays and parking structures.

RENEWABLE ELECTRICITY GENERATION CAPACITY

To find the annual electricity generation of the proposed array, an easy to use online calculator called PVWatts™ is freely available online from the National Renewable Energy Laboratory (NREL). By selecting the site location and providing orientation parameters, an estimate of annual energy generation and cost are quickly calculated for a given PV array size and direction. A summarization of the various PVWatts™ reports for the various arrays is included in Table 9.

City	Allentown
State	Pennsylvania
Latitude	40.65° N
Longitude	75.43° W
Elevation	117 m

PV System Specifications	Roof	Parking 1	Parking 2	Parking 3	Parking 4
DC Rating (kW)	77.5	28.8	28.8	28.8	28.8
DC to AC Derate Factor	0.77	0.77	0.77	0.77	0.77
AC Rating (kW)	59.7	22.2	22.2	22.2	22.2
Array Type	Fixed Tilt	Fixed Tilt	Fixed Tilt	Fixed Tilt	Fixed Tilt
Array Tilt	33.5	15	15	15	15
Array Azimuth	199°	189°	192°	205°	209°

Energy Specifications
Cost of Electricity: $0.09/kWh

PVWatts™ Results						
	Monthly AC Energy Generated (kWh)					
Month	Roof	Parking 1	Parking 2	Parking 3	Parking 4	Total
1	5737	1737	1731	1686	1662	12,553
2	6273	2068	2063	2032	2016	14,452
3	8554	2993	2989	2956	2939	20,431
4	9230	3413	3412	3400	3391	22,846
5	9230	3605	3604	3588	3581	23,608
6	8816	3540	3538	3524	3517	22,935
7	9540	3743	3740	3725	3720	24,468
8	8856	3338	3337	3324	3317	22,172
9	7924	2828	2826	2807	2797	19,182
10	7358	2434	2430	2389	2368	16,979
11	4781	1514	1510	1481	1467	10,753
12	4829	1451	1446	1405	1384	10,515
Annual Electricity Generation (kWh)						220,894
Annual Cost Savings						$ 21,205.82

Table 9: Total Electrical Generation and Savings of PV Array

The proposed PV system is expected to generate 220,894 kilowatt hours of electricity per year. At a cost of $0.09 per kilowatt hour, the array will save DeSales University $21,206 year through the reduction in utility power consumption.

LIFECYCLE COST ANALYSIS

Up-Front Cost Estimate

The PV array considered in this analysis is comprised of two main sections; the rooftop array and the parking lot Solar Trees®. These sections were estimated separately due to the difference in the systems' installed costs provided by the manufacturers, vendors, and industry professionals.

- Rooftop Photovoltaic Array
    - 310 panels × 250 $\frac{Wdc}{panel}$ = 77,500 Wdc
        - 77,500 Wdc × $3.68/Wdc[9] = **$285,200**
    - 100 kW SatCon Powergate Plus Inverter
        - **$45,900**[13]
    - Installation
        - $0.50/Wdc[9] × 77,500 Wdc = **$38,750**
    - Total Rooftop Installed Cost = **$369,850**
- Envision Parking Lot Solar Tree® Arrays
    - 8 Solar Tree® Structures × 14,400 $\frac{Wdc}{Structure}$ × $7/Wdc[1] Installed = **$806,400**
    - 135 kW SatCon Powergate Plus Inverter
        - **$49,900**[14]
    - Total Parking Lot Installed Cost = **$856,300**
- **Initial Cost of PV System = $1,226,150**

Tax Incentives

- Federal Investment Tax Credit (ITC)[3]
    - Tax credit in the amount of 30% of the total system cost
        - 30% × $1,226,150 = **$367,845**
- Pennsylvania does not offer any solar tax credits or exemptions in place, and rebate programs have recently been exhausted

Solar Renewable Energy Credits (SREC)

SRECs are credits given to investors of solar technology by the utility company. These credits are used as a type of currency and exchanged in a market. The government requires energy suppliers to buy a certain percentage of these SRECs from the photovoltaic resources, or pay them a large fine. Although the amount of SRECs available, and hence, the supply will increase, the government is expected to increase the SREC requirement of the utilities to balance the demand. For every 1,000 kilowatt hours generated by a PV array, one SREC is gained and able to be sold to the utility. There are many ways to exchange these credits, such as providers negotiating long term contracts with PV owners, on an auction, or on an exchange. The current average cost of SRECs in Pennsylvania is $180.39 per SREC[17]. This amounts to a yearly revenue of **$39,840**, and can be expected for the first 10 years of the system.

Cost Analysis

Solar installations are typically viable for a total lifespan of 25 years until the solar cells will need to be replaced. They also incur maintenance costs to ensure the glass films are clean and provide an unobstructed path for the sunlight. Figure 25 shows the lifecycle cost analysis of the entire PV system detailed above.

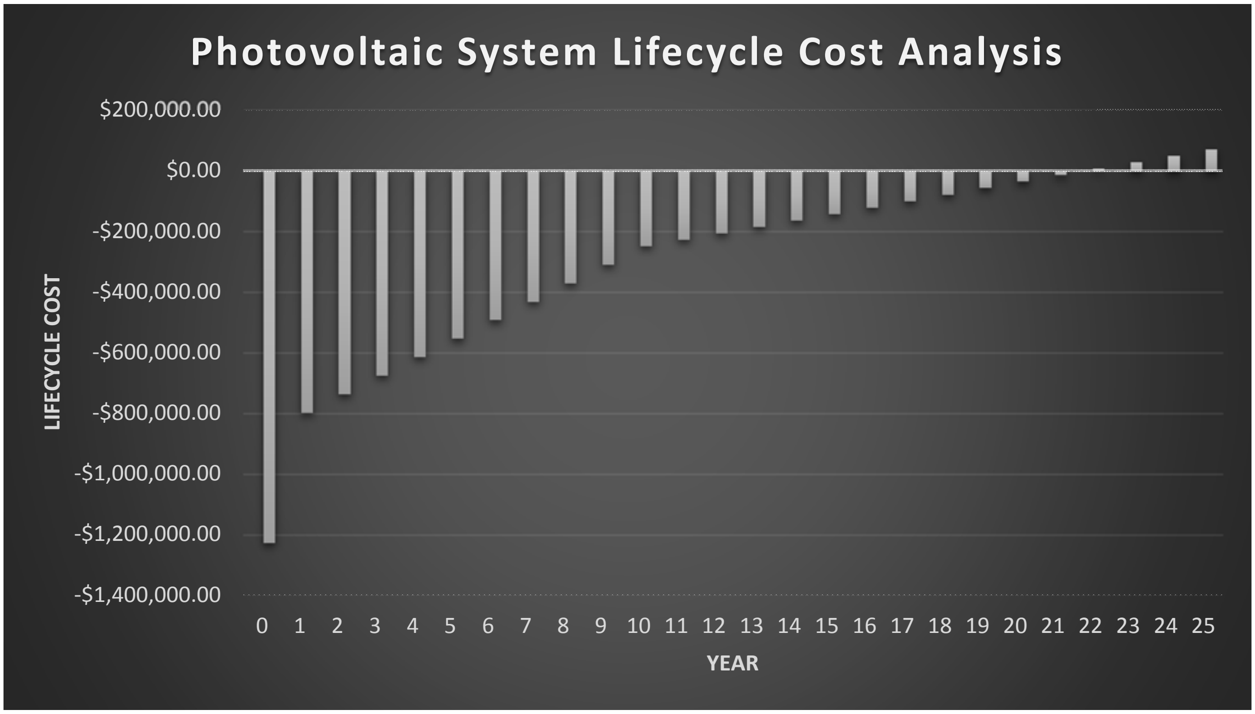


Figure 25: Photovoltaic System Lifecycle Cost Analysis

A third of the cost of the system was paid for through the federal tax credit and the available SRECs helped to pay for the initial cost of the system in the 22nd year. Though the system shows a return on investment of 5.7 percent over the 25 year period, the payback period is longer than would be preferred by most owners. This is a result of the premium paid per watt for the Solar Tree® arrays in the parking lot due to Envision's engineering costs, more difficult construction, and various materials needed for construction. Had the parking lot structures been excluded from consideration, the system would provide a 10 percent return on investment in which is paid back in the 11th year. The PV system's generation capacity would also be reduced by 59 percent, which may result in not producing at least 13 percent of the building's energy. Please see Appendix E-1 for the detailed lifecycle cost analysis performed.

LEED® ANALYSIS

Stated in the goals of this technical analysis was to determine the percentage of the Gambet Center's electricity that could be produced by on-site renewable energy. To calculate this, an estimate of the baseline load of the building must be used. Although the Gambet Center has not become fully operational, the Facilities Department was able to provide their expected electricity consumption in August 2013, which was comparable to the estimate of building electricity usage found in the results of Technical Analysis I.

Technical Analysis I used energy modeling as a conceptual design tool to make wiser decisions regarding sustainability in buildings. The results of the energy analysis for the Gambet Center shows an estimated annual electrical consumption of 781,313 kilowatt hours. For both the roof and parking PV arrays, the annual electrical generation is 220,894 kilowatt hours, or 28 percent of the building's electrical consumption. This far surpasses the 13 percent needed for all seven points to be obtained. If only considering the rooftop portion of the system, only 11.6 percent of the building's electricity is sourced by renewable technology. For any hope of getting LEED® Gold, all seven of the on-site renewable energy credits must be obtained.

RECOMMENDATION AND CONCLUSION

This technical analysis involved designing a photovoltaic grid-tie in system for the Gambet Center. A combination of traditional rooftop fixed tilt solar panels and Envision Solar Tree® structures for the parking lot provide a generation capacity of 220,894 kilowatt hours per year. Generating 28 percent of the building's electricity, the system would qualify for 7 LEED® points for on-site renewable energy, which are necessary to reach a Gold rating. The system requires a substantial initial investment of $1.23 million, however, the electricity savings and incentives allow the system to be repaid in the 22nd year of its 25 year lifecycle, ultimately making the university $70,250.

Although they provide a majority of the generation capacity of the system, the inclusion of the solar parking arrays negatively impact the payback period and return on investment of the system. On their own, the rooftop array has a much more favorable payback period, but only qualifies for 5 LEED® points. The final recommendation for the system is to install the rooftop array and one Solar Tree® parking canopy in order to provide the capacity of 15.7 percent of the building's electrical usage, while maintaining an acceptable payback period (15 years) and considerably higher return on investment (21%).

TECHNICAL ANALYSIS IV: ADVANCED LIGHTING CONTROLS

PROBLEM IDENTIFICATION

The lighting designers for the Gambet Center took special care to ensure the system included central lighting control equipment that helped reduce electricity use. This includes the use of dimming, and occupancy and daylight sensors throughout most areas of the building. The faculty offices do not provide dimmable lights, and could most likely utilize enough natural light during the day to decrease power consumption while maintaining acceptable light levels.

RESEARCH GOALS

The goal of Technical Analysis IV is to explore opportunities of expanding the lighting control system in the Gambet Center to reduce the electrical requirements of the lights. The design of the system will be revised and expanded for dimming capability. A measure of the electricity that is saved will be calculated and compared with the cost increases of the system to determine the financial feasibility of the upgrade. In addition, a final study of the effect the redesign may have on energy efficiency will be used to evaluate any changes to the LEED® scorecard.

METHODOLOGY

- Study current lighting control system to understand the setup, features, and areas for improvement
- Redesign system to include additional capabilities to decrease electrical requirements of the lighting system
- Calculate annual electrical consumption of the lighting system
- Find the energy savings of the system upgrade
- Provide lifecycle cost analysis for the upgrade
- Determine any gains in LEED® credits resulting from the redesign

RESOURCES AND TOOLS

- Internship experience
- Applicable Literature
- Industry Professionals

- Department Faculty

EXPECTED OUTCOME

The energy savings resulting from the upgraded lighting control system studied in Technical Analysis IV is expected to result in a considerable decrease to the electrical load of the lighting. It is hoped the reduction in electricity will be enough to increase the building energy efficiency by at least two percent, which is equivalent to one additional LEED® credit.

LUTRON QUANTUM® LIGHT MANAGEMENT HUB

DeSales University set the strict requirement for a sustainable design to the Gambet Center. Part of this included a sophisticated whole building solution to lighting control with Lutron Electronics' Quantum® Light Management Hub. The system is basically a panel box computer that controls light fixtures and peripheral devices from the centralized processor. With Quantum®, lights can be controlled through a combination of a timeclock, in-room wallstations, occupancy sensors, and remote control from a PC workstation or iPad.

Quantum® Hubs

Figure 26

Quantum® Hubs come with either one or two processors depending on the requirements of the system. A general rule of thumb is for every one or two floors to have its own Hub, subject on the individual floor area and level of control. The standard Quantum® Hub (QP2) is customizable to the needs of the system, and allows for one or two processors and one to eight Ecosystem® "loops". Every processor has two "links" with the ability to connect 99 control devices (sensors, wallstations, etc.) each. Each Ecosystem® loop has a capacity of 64 connected ballasts or Ecosystem® controls. Luminaires equipped with Lutron Ecosystem® Ballasts are able to connect directly to the Hub, making design and installation much easier, while helping to reduce the system cost. Another major benefit of adopting Ecosystem® is there is no need for lighting zones because each Ecosystem® device can be controlled independently by the Hub. The terms "loops" and "links" are merely nomenclature given to the daisy-chained wiring of the Ecosystem® and Quantum® System (QS) devices, respectively. A job-specific database is then created for every Quantum®

system installed to exactly dictate how every input from the system should affect the lighting. Lutron has since developed a miniature Hub (QP3, shown in Figure 26) that consists of one processor and no Ecosystem loops that allows for a more cost effective solution to smaller implementations of Quantum®. The system originally designed for the Gambet Center utilizes one of the QP3 Hubs on each floor for their light management solution.

Energi Savr Nodes (ESN)

With the exception of Ecosystem® capable fixtures, the luminaires are not directly wired to the Hub, but instead to what is called an Energi Savr Node, or ESN. ESNs are QS link devices that are used as an interface between the Quantum® control system, and the input electrical power to the individual lighting zones. ESNs come in two varieties that provide connection to Ecosystem® capable fixtures or non-Ecosystem® ballasts for on/off switching.

The decision to use the smaller QP3 Hub for the Gambet Center eliminated the possibility to wire Ecosystem® ballasts directly to the Hub. Therefore, one of the previously mentioned ESNs that connects additional Ecosystem® loops to the system was necessary to accommodate the 18 applicable luminaires. With only a small fraction of the building's lighting system compatible with Ecosystem®, ESNs that connect to the individual lighting zones must be used.

For the fixtures not compatible for use on the Ecosystem® loops, the alternative type of ESN is used. Only four zones can be wired to each ESN, requiring 26 of these units for the Gambet Center. An expanded ESN of this type, but not used on this project, is also available that contains an additional four zone outputs for 0-10 volt channels (usually for LED type fixtures). Again, the ESNs are connected to one of the QS links on the Hub processor. From the electrical panelboard, the particular lighting circuit is connected to the ESN input feed, where it is interfaced with one of the four zone outputs of

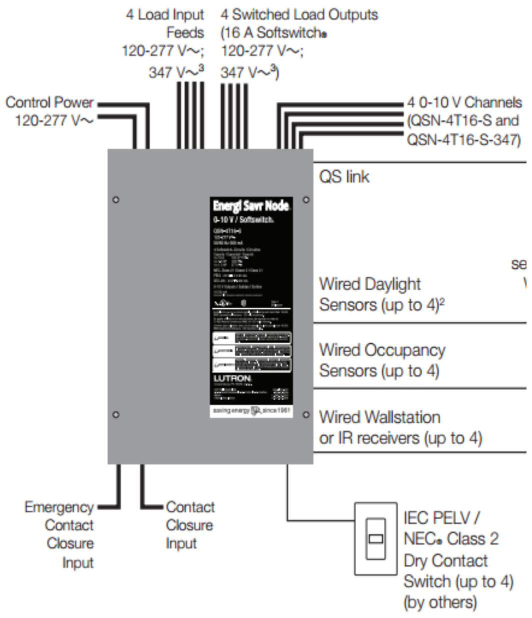


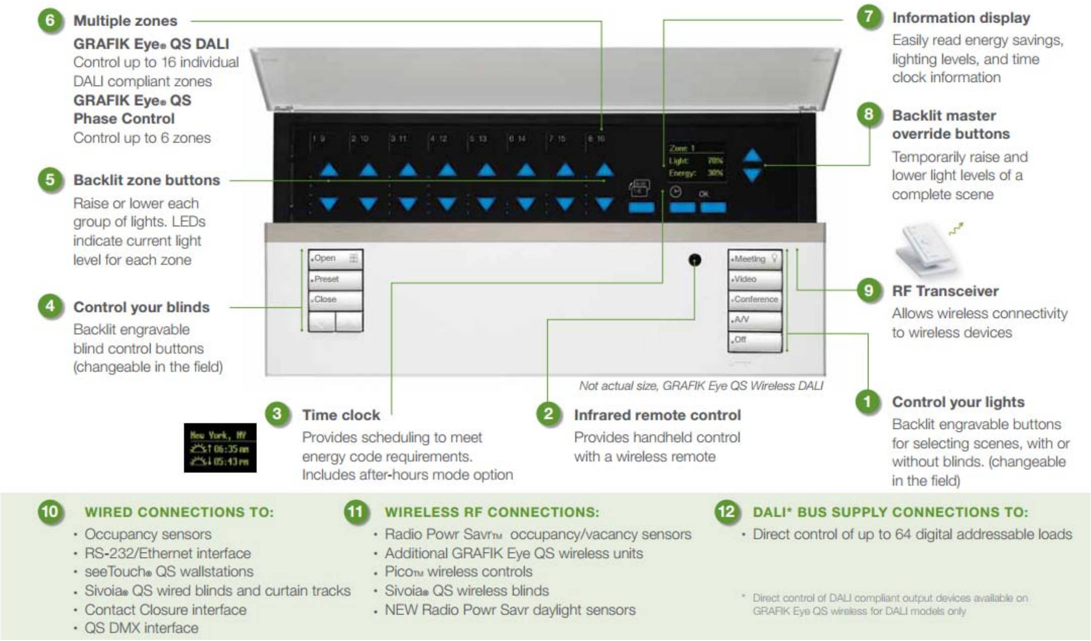
Figure 27: Lutron Energi Savr Node

the ESN. The wiring diagram of this type of ESN (shown with the four 0-10V channels) is shown in Figure 27.

Another option for controlling fixtures that are not compatible with Ecosystem® is to use a Lutron brand Panel and create a panel link out of one of the available links. When a panel link is created, it will no longer work to connect QS devices to the Hub. The Gambet Center utilizes a panel to connect all of the exterior lights to the system and control them using the timeclock functionality of the Quantum® software. Similar to exterior lighting, these panels are used mainly for premier building spaces such as atriums, lobbies, and auditoriums.

Grafik Eye®

To add dimming functionality to the system, the Gambet Center uses another Lutron product called the Grafik Eye®. When the Grafik Eye® was introduced, it was the premier stand-alone lighting control device for a single room solution. As Lutron continued to develop more expansive and centralized control systems, the Grafik Eye® eventually evolved to become compatible with Quantum®. A Grafik Eye® can be thought of as a QS link device that acts as a small scale Quantum® Hub. Although available in many configurations, the Grafik Eyes® used in the Gambet Center are able to connect and control up to six switched lighting zones and one Ecosystem® loop. A wallstation keypad is built in, with the ability to connect up to four additional QS devices.



⑥ **Multiple zones**
GRAFIK Eye® QS DALI
Control up to 16 individual DALI compliant zones
GRAFIK Eye® QS Phase Control
Control up to 6 zones

⑤ **Backlit zone buttons**
Raise or lower each group of lights. LEDs indicate current light level for each zone

④ **Control your blinds**
Backlit engravable blind control buttons (changeable in the field)

⑦ **Information display**
Easily read energy savings, lighting levels, and time clock information

⑧ **Backlit master override buttons**
Temporarily raise and lower light levels of a complete scene

⑨ **RF Transceiver**
Allows wireless connectivity to wireless devices

Not actual size, GRAFIK Eye QS Wireless DALI

③ **Time clock**
Provides scheduling to meet energy code requirements. Includes after-hours mode option

② **Infrared remote control**
Provides handheld control with a wireless remote

① **Control your lights**
Backlit engravable buttons for selecting scenes, with or without blinds. (changeable in the field)

⑩ **WIRED CONNECTIONS TO:**
- Occupancy sensors
- RS-232/Ethernet interface
- seeTouch® QS wallstations
- Sivoia® QS wired blinds and curtain tracks
- Contact Closure interface
- QS DMX interface

⑪ **WIRELESS RF CONNECTIONS:**
- Radio Powr Savr™ occupancy/vacancy sensors
- Additional GRAFIK Eye QS wireless units
- Pico™ wireless controls
- Sivoia® QS wireless blinds
- NEW Radio Powr Savr daylight sensors

⑫ **DALI* BUS SUPPLY CONNECTIONS TO:**
- Direct control of up to 64 digital addressable loads

* Direct control of DALI compliant output devices available on GRAFIK Eye QS wireless for DALI models only

Figure 28: Typical Grafik Eye® Functionality

The dimming ability of the lighting control system is mostly done through the use of individual Grafik Eye® units in the snack area, conference rooms, classrooms and lecture hall. The exceptions are the control room and reception area, which are controlled from the Ecosystem® loop of the ESN-2ECO described above. Fixtures in conference rooms, classrooms, and lecture hall are connected to the Ecosystem® loop of the Grafik Eye®. The snack bar and lecture hall also utilize the zone outputs to control the non-Ecosystem® fixtures; however, the ability to dim is not built-in to the Grafik Eye® unit. Therefore, a phase adaptive module that enables dimming must be interfaced between the Grafik Eye® and lighting zone.

Various lamp types, such as incandescent and florescent, require different technology for dimming. Incandescent lamps can be dimmed by simply interrupting the electrical current at least 60 times per second to lower the luminosity of the bulb with no noticeable flicker. Florescent, metal halide, and LED lamps rely on a ballast or driver to regulate the power to the lamp. Consequently, the method used for incandescent lamps will not work, and dimming is dependent on the ballast or driver of the fixture. In order for Quantum® to work properly, these interfaces are necessary to provide dimming to the zone. A diagram detailing all the features of the Grafik Eye® can be seen above in Figure 28.

QS Link Devices

There are many types of devices that connect to the QS link that add the ability to control the lights. Usually, these devices consist of wallstation keypads, Grafik Eyes®, or ESNs. Another device often found on the QS link is known as a Quantum® Sensor Module (QSM). QSMs are ceiling mounted modules that allow the connection of up to four sensors, usually occupancy or daylight sensors, to interact with the Quantum® Hub. They are also radio-frequency receivers that can process inputs from Lutron's compatible wireless devices. Figure 29 shows some examples of QS devices used for the Gambet Center.

Occupancy Sensor Quantum Sensor Module Daylight Sensor Wallstation

Figure 29: Quantum® System (QS) Devices

UPGRADE TO LIGHTING SYSTEM

While a majority of the building's lights are controlled this way, all are not controlled by the Quantum® system. The faculty office spaces around the perimeter of the building have stand-alone occupancy sensor wall switches to control the lights. There are a total of 80 rooms that could be added to the Quantum® system to take advantage of additional energy savings. The choice to use the QP3 drastically limits the expandability of the system, so it may be necessary to upgrade the Hub to the standard QP2 model. This will require a significantly higher cost if necessary, so the current system may need to be reorganized.

A copy Lutron submittal drawings can be found in Appendix F (electronic version only). From these, it was discovered that many of the spaces controlled by the Quantum® system did not include dimming, such as the nursing patient rooms and anatomy labs. After further consideration, it was decided this was best because when people are using these rooms, the full light level is usually desired. After realizing the original scope of the lighting controls was appropriate, the focus shifted to finding how to incorporate the stand-alone controls of the faculty offices, breakout and conference rooms into the Quantum® system.

There are 198 (Type A or A1) light fixtures to be added to the system, all of which require two 28 watt T5 florescent lamps. Cross referencing the fixture types on the current Ecosystem® link, it was found that both Type A and Type A1 fixtures are Ecosystem® capable. The existing QSN-2ECO, the Energi Savr Node that provides Ecosystem® loops to be added to the QS link, will not have the capacity for this expansion. As a result, another unit is required for the remaining fixtures. This adds one additional device to Link 1-A, leaving only four additional devices able to connect.

A review of one line drawings to take off the device quantity on the links. The results of this can be seen in Table 10.

Hub #-Link X	QS Devices
1-A	94
1-B	Panel Link
2-A	75
2-B	92

Table 10: Quantities of QS Link Devices per Link

Considering 80 rooms would need to be added to the current system, it is clear the 36 device openings of the currently designed system would not be sufficient. With no spare links available, an upgrade to the more expensive QP2 would be required if this option was selected. It was already said that this was undesirable because it adds a lot of cost, which is harder for the owner to accept. When describing the QSMs above, it was explained that each module has the capability of receiving radio frequency (RF) signals from Lutron's selection of wireless devices. More specifically, each QSM can be simultaneously configured to control up to 10 wireless occupancy sensors, daylight sensors, and Pico® wireless keypads up to 60 feet away. The Gambet Center has 29 QSM devices scattered throughout the building, providing ample device capacity and uniform signal coverage. It should be noted that the wireless devices are battery powered and have an expected lifespan of 10 years.

To get the maximum energy savings out of the system, wireless occupancy and daylight sensors will be used in conjunction with wireless wall stations that provide automatic control based on light levels and occupancy. They also give the occupant their own control that is often attributed to a healthier, happier, and more productive individual. A typical office would have one of each device. Offices without large windows do not include daylight sensors. The breakout and conference rooms would have a single occupancy and daylight sensor, but a wireless keypad near the entrance of both doors. This results in a total of 76 occupancy sensors, 65 daylight sensors, and 80 Pico® wall controls. Fortunately, the ESN is the only piece of equipment that will need to be connected to the system. An additional day of field service will be required by Lutron for their technicians to commission the system is programmed correctly and fully functional. The wireless option is also beneficial in the sense that installation is much quicker and less expensive because there is no wiring to be connected. If an average of 10 devices can be installed per hour, the entire upgrade could be completed in approximately 25 hours.

LIGHTING LOADS

To determine the energy saved from the original lighting system, a full takeoff of the fixture types was conducted for the building. The full takeoff is available in Appendix G. Applying the quantities of fixtures to their input wattages and assuming the lights of the Gambet Center are on for an average of 10 hours per day, the lighting system consumes 216,500 kilowatt hours of electricity annually with no lighting controls in place. The Quantum® system originally designed saves 27,212 kilowatt hours per year, or 13 percent of this baseline load.

The energy saved when using lighting control strategies is highly variable and depends on the sophistication of the system. A top of the line Quantum® system has the potential to provide energy savings up to 60 percent. The upgrade suggested in the previous section can be expected to have savings of 10 percent for personal dimming control[7,18], 15 percent for daylight harvesting[18,19], and 15 percent for the occupancy sensors[8,18]. These figures are then applied to the appropriate fixtures, where an additional savings 14,878 kilowatt hours is calculated. This equates to a 34 percent decrease in electricity use of the added luminaires. The expansion of the lighting control is 8 percent more efficient than the originally designed system. Similarly, the new system, as a whole, is 19 percent more efficient than the baseline load. A summary of this data is shown below in Table 11.

Lighting Load Summary	
Baseline Lighting Load	216,500 kWh
Current Energy Savings	27,212 kWh
Current Lighting Load	189,287 kWh
Upgraded Energy Savings	14,878 kWh
Upgraded Lighting Load	174,409 kWh
Energy Reduction Percentage	
Current Savings / Baseline Load	13%
Upgrade Savings / Current Load	8%
Total Savings / Baseline Load	**19%**

Table 11: Lighting Load Calculation Summary

LIFECYLCE COST ANALYSIS

A lifecycle cost analysis comparing the cost of implementing the improved lighting control system to the energy savings. At the request of Lutron Electronics Company, Inc, individual and system costs will not be published.

Initial Cost

The up-front cost of the add-ons to the system is dependent upon the cost of the wireless equipment, additional Energi Savr Node, and commissioning costs. The standalone equipment intended for the offices and conference rooms must also be considered; the cost of which needs to be subtracted from that of the upgrade. The option of controlling these spaces through Quantum® results in an increase of **$6,614.**

Energy Savings

The new system offers an added energy savings of 14,878 kilowatt hours. At an electric rate of $0.09 per kilowatt hour, DeSales will see an annual decrease of $**1,339.**

Cost Analysis

A savings of $1,339 per year allows the upgrade to pay for itself within 5 years. Assuming the system has a lifecycle of 15 years, DeSales University would have saved $13,471 from the addition of the system. The bar graph in Figure 30 provides a visual representation of this data.

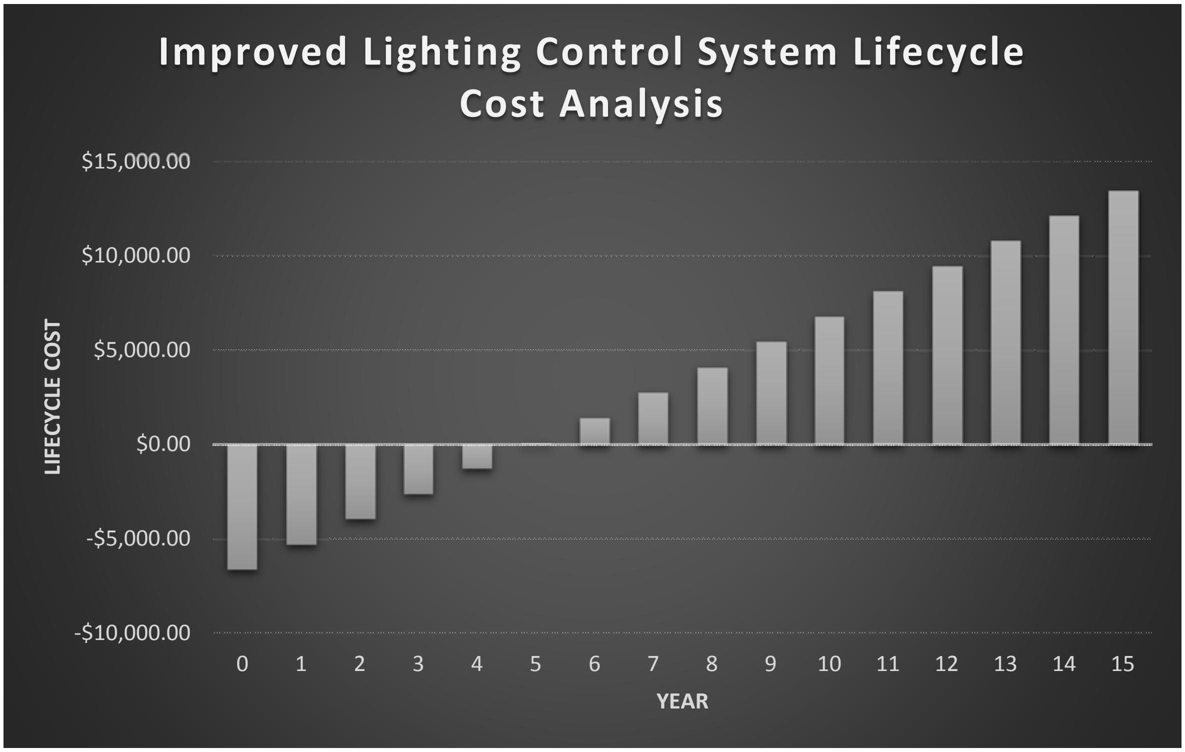


Figure 30: Quantum® Upgrade Lifecycle Cost Analysis

LEED® ANALYSIS

The reduction in energy use of the lighting system can be taken and used to find the impact it has on the energy efficiency of the entire building. Information resulting from Technical Analysis I will also be used in regard to the entire building performance numbers. From Technical Report I, the total yearly electrical use for the building is 853,775 kilowatt hours. Information obtained from the Facilities Department at DeSales University predicts the Gambet Center to consume 775,000 kilowatt hours per year. When considering the software used in Technical Analysis I does not account for efficient lighting systems, the annual power use must be modified using the more accurate results of the lighting load calculations. Adjusted for the baseline lighting system, the annual power consumption is 781,313 kilowatt hours, which is relatively close to the expected usage.

The energy savings from resulting from the Quantum® improvement, is equivalent to a 1.9 percent decrease in the total electricity consumption of the building. Assuming 53% of the building's energy by cost (Technical Analysis I), a 1.9 percent increase would not be substantial enough to increase the building's energy efficiency the 2 percent needed for an additional LEED® credit.

RECOMMENDATION

Although the upgraded system failed to obtain additional LEED® points, the implementation was effective in achieving enough energy savings to provide a satisfactory payback period of 5 years and return on investment of $13,471 after 15 years. Installation of the wireless option is easier and can be completed in 25 man-hours, having minimal impact on the schedule. As a result, it is recommended that DeSales University expand the Quantum® Total Light Management System to include the faculty offices, breakout, and conference rooms.

FINAL CONCLUSIONS

The results of the previous Technical Analyses predict an increase of 7 LEED® points, for a hypothetical total of 57 credits able to be achieved by the Gambet Center. All 7 of these credits are attributable to the on-site photovoltaic array recommended in Technical Analysis III. Hence, the green roof and upgraded lighting control system did not have a substantial effect on the overall energy efficiency of the building. When referencing the LEED® Scorecard in Appendix A, it can be seen that the Gambet Center is eligible for credits in Certified Wood, Innovative Wastewater Technologies, and the Optimize Energy Performance categories.

The use of wood is not extensive in the Gambet Center; however, there are wooden lockers that line the hall, wooden cabinets in the exam rooms, along with other finishes. If these wood-based products are made with wood certified in accordance with the Forest Stewardship Council's requirements, it is possible for the Gambet Center to obtain an additional LEED® credit.

Another possibility to achieve two additional LEED® points is to integrate a rainwater harvesting system with the stormwater drainage in an effort to substitute 50 percent of the water used to flush the toilets with collected rainwater. Although costs vary depending on the storage capacity and size of the system, they usually range in cost from $140,000 to $200,000 dollars for a system with a 10,000 gallon tank suitable for the Gambet Center.

The way to achieve the most LEED® credits is to implement the heat pump alternative explored in Technical Analysis I. The energy analysis showed a 14 percent decrease, by cost, in the energy use of the building. Assuming the ground source heat pump is 44 percent[23] more efficient than the existing system, an increased energy efficiency of 6 percent can be achieved. This increase improves the energy performance of the building by 24 percent, which qualifies for 6 additional LEED® credits, easily reaching the Gold status.

Again, the ground source heat pump requires a substantially higher cost to install than the original system, and clearly shows that it is common for the cost to construct a truly sustainable building gets much higher when aiming for a LEED® Gold or Platinum status. Using an estimated increase of $7.69 per square foot over the packaged gas VAV system, the heat pump adds $584,440 to the mechanical cost of the building.

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