Jeremy Jewart
Construction Management Option

Baldwin High School
Pittsburgh, PA

Dr. Riley
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Thesis Presentation
Spring 2007

Senior Thesis

"Green Schooling and Its Applications"

The Pennsylvania State University

Thesis Abstract (Existing Building)

Project Cost: $64.4 million
Size: 395,667 ft^2

# of Stories: 3

Completion:
January 2006 - February 2009

Delivery Method:
CM Agent

BALDWIN HIGH SCHOOL
PITTSBURGH, PENNSYLVANIA

Jeremy Jewart – Construction Management
http://www.arche.psu.edu/thesis/eportfolio/2007/portfolios/JKJ114/

PROJECT TEAM

Owner:
Baldwin Whitehall School District

Consultant/Construction Manager:
PJ Dick

Architect/Engineer:
HHSDR Architects and Engineers

General Contractor:
Yarborough Development, Inc.

Electrical Contractor:
Lighthouse Electric

HVAC:
Wayne Crouse, Inc.

Plumbing Contractor:
Mechanical Contracting, Inc.

ARCHITECTURE

- Five phase renovation
- Existing structure has remained intact since 1939
- 80% of school to be of new construction
- Roman/Greek style and 21st century Arch.
- Skylights added for internal day lighting

BUILDING ENVELOPE

- Exterior wall system braced by structural steel frame
- 10" CMU block
- External brick facade with glass ribbon windows
- Visible concrete columns

STRUCTURAL SYSTEM

- New retaining wall supports entire southwest and southeast faces of building
- Steel columns vertically span the height of three floors
- Lateral support comes from both wide flange beams and open web steel joists
- 12" thick wall footings, 4"- 6" slab on grade, 6"x 6"x # 8 W.W.F., 6" concrete leveling pads

SPECIAL FEATURES

- 2 gymnasiums, a new swimming pool, larger classrooms and hallways
- State-of-the-art security and air conditioning systems in the auditorium
- 2 interior courtyards, a new athletic entrance, and a brick paved plaza/walkway

Table of Contents

Executive Summary

This thesis report intends to illustrate the research of green schooling design vs. conventional school design. The principles researched were then applied to my specific building, Baldwin High School. Within this document you will find the research of applying green construction incentives to school buildings and the benefits of which this methodology provides. The issues of sustainability and the implications of what a high performance school suggests are the sole reasoning behind this thesis. After successful research has been illustrated you will then find two analysis sections of the report. These analyses's will then offer alternative methods of construction –which support the ideology of implementing green building processes into design. The first analysis section takes into regard the benefits of green schooling. It is the design portion of my thesis and here you will find the means and methods associated with a green roof system. The original plans and specifications do not include a green roof within Baldwin's design criteria. This gives ample opportunity to suggest, design, and reciprocate the benefits of a green roof construction. The second analysis section utilizes the findings from both the first analysis section and research section of the technical document. From the conclusions arrived at in both sections, precedence was set to examine the benefits of an alternative material selection for the already established and estimated item cost of windows. Therefore, this analysis will act as a secondary analysis to determine how a more environmentally conscious window selection can be used in design with relatively no cost increase.

Project History

Baldwin High School

Client Information

The owner of this project is the Baldwin-Whitehall School District. The junior/senior high school happens to be 1 of 5 buildings that the district is primarily in charge of maintaining. Responsibilities require overseeing three elementary schools, a middle school, and the high school. As an owner they are somewhat knowledgeable, but require a good deal of assistance based on the magnitude of the project. By replacing 80% of the school with new construction, the hiring of a CM Agent should prove quite beneficial. Continuing to provide a challenging educational program in a safe and caring environment are goals that the district would like to keep intact. A consultant insures that these goals will be met and that this educational facility will be brought up to 21st century standards.

During phase I of the project, unexpected excavation and temporary facility costs accumulated delays and required the drawing of money from the $1.126 million project contingency fund. Public financing will provide funding for the project, which will be paid for by utilization of 25 year bonds. The state Department of Education is expected to reimburse the district for about 25 percent of the principal amount of money burrowed.

Location

The Baldwin-Whitehall School District is a suburban, residential area located eight miles south of downtown Pittsburgh, (see Figure 1). The Baldwin-Whitehall (junior/senior) High School renovation project is providing a more up-to-date and aesthetically pleasing look to the school. The building structure, which has remained intact since its origin in 1939, will have an estimated $64 million overhaul within a three year time period.

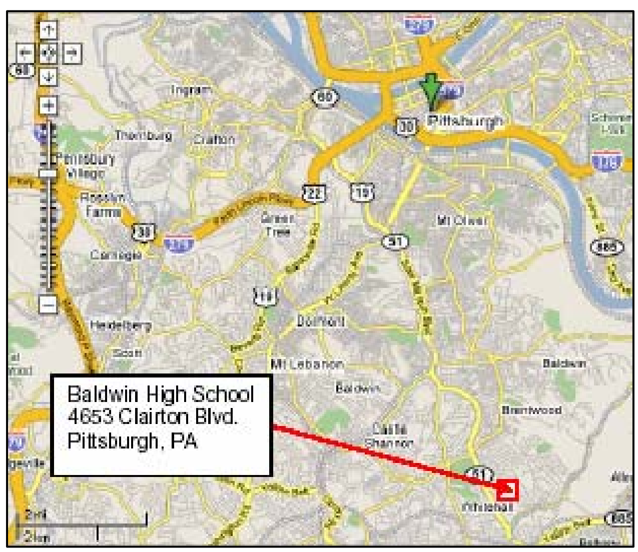


Figure 1. Baldwin High School Location

Sequencing Plan

The renovation will utilize a five phase sequencing plan to enhance the existing building both internally and externally. Upon completion, nearly 80% of the structure will be of new construction. The school district elected PJ Dick as their CM consultant and HHSDR as their project architect. A renovation committee was organized to interact readily with the school board and to compile necessary budgetary concerns.

Delivery Method

Baldwin high school is being delivered using a CM Agent type of delivery method. PJ Dick Inc. was chosen to occupy the CM role while providing recommendations and guidance to the school board. The school district is a relatively inexperienced owner, when dealing with such a large-scale project. Therefore, utilizing a consultant for major sub-contractor interaction will be pertinent. This process allowed the school board to select the building type they wanted and then seek competitive bids on the project. The hiring of an experienced architect will also alleviate complexities during the designing and construction processes of the renovation.

Project Cost Evaluation

Project Cost Evaluation

Construction Costs

Sitework	$4,853,000
Concrete	$2,651,000
Masonry	$4,459,000
Metals	$6,178,000
Wood & Plastics	$315,000
Thermal and Moisture Protection	$3,828,000
Doors and Windows	$2,301,000
Finishes	$5,231,000
Specialties	$1,094,000
Equipment	$821,000
Furnishings	$2,121,000
Elevators	$164,000
General Conditions/Profit	$1,701,000
Liability Insurance	$432,000
Contractor Bonds	$361,000
HVAC	$7,351,000
Plumbing	$2,985,000
Electrical	$6,355,000
Fire Protection	$650,000
Stage Equipment	$35,000
Data Cabling	$666,000

Actual Cost:	**$54,400,000** **$137.49 per SF**	**Total Project Cost:**	**$64,400,000** **$162.76 per SF**

Figure 2. Project Estimate (General Trades)

Building Systems Summary

Baldwin High School is a renovation and nearly 80% of the building is to be of new construction. Because of this, heavy demolition work is required for the site. Tearing down parts of the existing building includes the removal of masonry, concrete, and structural steel. Precautions for asbestos were also of particular interest due to the building being an educational facility. All materials that are demolished will be removed to neighboring landfills and recycling

Demolition

Phase I of the project required demolition of the existing pool and locker structure. Erection of a steel frame became the foundation for the new gym and new locker room area. The steel columns are held in place by concrete footers and vertically span the height of three floors. Lateral support comes from both wide flange beams and open web steel joists. All beams are moment connected to columns. All supported floor slabs are composite slabs.

Structural

Any cast in place concrete will be placed by truck and chute for both above and below grade construction. For this project spread footings, grade beams, slab-on-grade, piers, and stair erection will be constructed via a cast in place method. Cast in place concrete walls will also range from a thickness of 10”-20”. For construction of curbs and sidewalks a hand trowel will be used to make sure all surfaces are of equal grade.

A steel frame will be used for the bulk of the facility’s structural stability. Utilization of wide flange beams and columns will suffice for both the exterior support steel and gym framing. Accompanying the steel structure will be concrete and masonry bearing walls. The majority of the masonry work will be seen as the veneer exterior of the building. CMU walls can be found throughout the interior of the structure and will support the elevated floor slabs and composite metal decking. Connections are attained by way of bolted steel angles. Segmental concrete facing units are used for the curved and unique underground retaining wall which lies beneath the perimeter of the building.

Mechanical

The mechanical system will utilize variable air volume boxes with hot water reheat coils, water boilers, and air-cooled condensers. Most of the mechanical elements can be located on the roof or in the basement of the new building. New air handling units can be found on the auditorium and gym roofs, as well as the interior of the pool area. Demolition of the existing boiler room and construction of the new one will take place during Phase I of the project. Fire protection will be of great importance and a new alarm system will be installed throughout the high school. Preferred Fire Protection was the specialized contractor elected to install the new system.

Electrical
The electrical system will branch off of the existing power supply and a series of new transformers will be installed. The transformers will convert the incoming electricity from 5KV down to a 480/277V three-phase system. Some areas will also call for a 5KV to a 208/120V system. Power distribution will then be run both above and below grade. A wireless electrical signal will also be installed and ran to the high school stadium. The auxiliary sound system will be installed in all areas of Phase I construction. The sound system will be accompanied by new voice and data cabling systems, which are all major additions to the facility. Subsequently, a new back-up generator will be needed for temporary power outages. Being that this is a school building; the risk of having unavailable power is not one that can be taken.

Site Work
Phases I and 2A of the project were excavated due to the installation of the new gym, natatorium, and pool areas. Inclusion of new fire hydrants, underground domestic water tanks, and a new sanitary manhole were some of the big-ticket items for this area of the project. Extensive underground sanitary piping and relocation of existing natural gas piping will also need to take place. During other phases of the project, minimal excavation will need to occur because a large portion of the site has been previously excavated. For the areas that will need to be, most of the drainage will be tied into existing 15” storm pipes and drains. A new bleeder drain line was also installed to retain much of the sediment runoff that may accumulate from construction.

Research

Costs and Benefits of Providing Green Schools

Overview
This study's purpose is to provide substantial evidence that will support the notion that a failure to invest in green technologies is not financially responsible for school systems. The reduction in life-cycle cost as well as the environmental benefits of "going green" will be illustrated throughout this form of documentation. The conclusions provided show that by building green we can all profit. The research outlines the rationale behind why green school design provides a cost-effective way to enhance student learning. It not only focuses on the business and fiscal advantages of today's school construction, but also addresses the environmental and health benefits as well. It shows how cost effective schools start with good design and the results that come from this design upon final project completion.

Motivation for Research
The selected building, of which my thesis pertains to, is Baldwin High School located in Pittsburgh Pennsylvania. It consists of a five phase renovation sequence and is currently near completion of phase two of the process. My interest in this specific area of "green" research was initially provoked by acknowledging the various conditions of the project from a design perspective. More specifically, that this project is a school renovation in excess of $64 million as well as the decision of the owner to not achieve the recognition of occupying a LEED certified building. The opportunities that surround the possibility of achieving this rating pose indefinite motive to identify exactly how beneficial the construction of a green school could be. Pertaining to a broader spectrum of reasoning, it was also identified that nearly 55 million students spend their days in schools that are often unhealthy and that restrict their ability to learn.

Discouragements of Building Green
In today's building industry cost plays a prominent role in determining many aspects of both design and construction. With this in mind, building green high performance schools generally cost more. This has been considered a major obstacle during a time of limited school budgets and an expanding student population. A survey by Turner Construction Company of 665 senior executives highlights this reasoning in an attempt to illustrate the downfalls of green building. It was found that most executives are discouraged from undertaking green construction due to concerns surrounding the cost and the lack of available information on the financial benefits of it. Below, (Figure 3) depicts this methodology and sets a precedent for the industry's conservative way of thinking.

Typically, conventional schools are not designed to produce an environmentally friendly structure; but rather to strictly meet building codes and provide a product that is aesthetically pleasing. It should also be recognized that few states regulate indoor air quality and/or provide ventilation standards for schools. In turn this provides companies with an even stronger argument to nullify the incorporation of "building green" into design. Therefore, my research intends to identify exactly how much more building green would cost and if the production of this green result would essentially be cost effective.

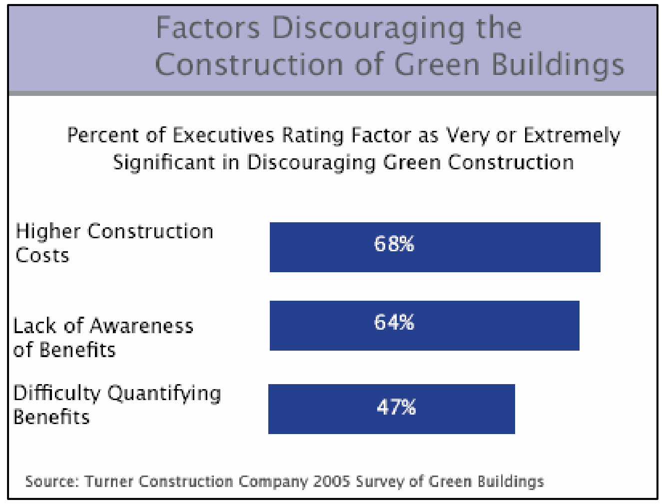


Figure 3. Factors Discouraging Construction Source: Turner

Green Schools vs. Conventional Schools

Financial Benefits (Background)

Building green primarily questions a more environmentally friendly construction industry; however because this sector seems to rely heavily on cost, this section of my report will illustrate some of the financial benefits as well. For a conventional vs. green school comparison it should also be understood of exactly when that cost occurs during the project. When comparing the two, many green building upfront costs are minimized through observation of their entire life-cycle cost. More specifically, conventional schools have lower design and construction costs and higher operational costs, whereas green schools usually have higher design and construction costs and lower operational costs. This is particularly useful for identification of the financial benefits of a building over the entire time it will be in use. A recent evaluation of the impact of LEED adoption illustrates this point. It was developed for the Portland Energy Office and found that regional life cycle savings from adopting 15 individual green building technologies was over 8 times as large as the direct first cost of these measures (Green City.)

Financial Benefits (Reduced Savings Elsewhere)

Upfront costs are usually the cause of hesitation for the implementation of green design. As previously stated, the life-cycle costs and savings is typically what offsets these initial upfront costs throughout design development. Items such as the reduced cost of HVAC systems or a reduced code compliance cost are frequently overlooked. Similarly, a green roof or greywater system can avoid the capital cost of a water retention system which is normally required to comply with water codes. For example, a model green school developed by the architectural firm OWP/P included a green roof that allowed the building to avoid a water retention system, providing savings sufficient enough to reduce the school cost premium to 1% (Green City.) The “green premium” is the initial extra cost to build a green building when compared to a conventional building. A 2004 Massachusetts state report found that savings from lower overall energy prices due to lower energy demand from use of energy efficiency and renewables were quite impressive. The total direct and indirect energy cost savings from a new green school compared with a conventional school is $9/ft2. Total direct and indirect energy cost savings from a green as compared to a conventional upgrade of an existing school would be $7/ft2 (O’Connor.) These savings will be further elaborated on in the following two sections of this document.

Financial Benefits (Energy Savings Direct Costs)

The direct costs of energy savings can be illustrated via a report that was drawn from 30 green schools built in 10 states between the years of 2001 to 2006.

> This table can be viewed in Appendix A which has been incorporated at the end of this thesis. It should be noticed that these schools, on average, maintained a 1.65% cost premium for implementation of green design in their buildings. However, this initial cost can be weighed against the fact that these same schools also experienced a 33.4% saving in energy costs when compared to conventionally designed schools (Kats.)

Typical energy performance enhancements include more efficient lighting, heating and cooling systems, and a greater use of day lighting and sensors. This results in lower energy prices and provides direct cost savings in the form of lower bills to the school.

Financial Benefits (Energy Savings Indirect Costs)

Sometimes more importantly than the direct costs of energy savings are the indirect costs. This is primarily due to the fact that they are normally not accounted for in energy efficient cost analyses. For instance, in an individual school, this specific price impact is not measurable, but state-wide or nationally, the reduced energy consumption in schools could be substantial. Knowing that the average electricity and gas price has risen over the last 3 years by 6% and 14% per year, respectively, gives incentive to reduce these costs via green design. It is estimated that over a 20 year period benefits of lower energy prices could result in $6/ft2 of energy savings. A 2005 report from Lawrence Berkeley National Laboratory found that “a 1% reduction in national natural gas demand can lead to a long-term average wellhead price reductions of 0.8% to 2%” (Wiser.) This implies that a reduction in consumption could theoretically induce a reduction in long-term prices equal to 200% of the initial cost.

Environmental Benefits (Background)

The benefits that green schooling may provide environmentally are the primary reasoning behind adopting this type of building methodology in the first place. Residential, commercial and industrial buildings use about 45% of the nation’s energy, including about 75% of the nation’s electricity. Air pollution, from burning fossil fuels to heat buildings (natural gas and oil) and to generate electricity for these buildings (by burning coal, natural gas and oil) imposes enormous health and environmental costs (Kats.) Therefore the need to recognize these statistics and adhere to the benefits of building green becomes increasingly more apparent. The advantages of emission and wastewater reductions, accompanied by the benefits renewable energy may possess, are attributes green schooling offers that conventional schools can not.

Environmental Benefits (Emissions Reductions)

The building sector of the American economy produces over 40% of CO_2 emissions; which is the second largest next to China. By reducing the electricity and gas use in buildings this will in turn provide lower emissions of pollutants (due to the avoidance of burning fossil fuels). CO_2 is the primary cause of global warming and heat related deaths. Scientists have also concluded that virtually all of the world's climate change has been due to these same human caused emissions (Intergovernmental.) The USA is noted as being responsible for about one quarter of global greenhouse gas emissions. If we want these numbers to go down a large part of the solution will be changing the perspective of the building industry as a whole.

As a rough estimate, a green school could lead to the following annual emission reductions per school:

- 1,200 pounds of nitrogen oxides (NO_x) (a principal component of smog)
- 1,300 pounds of sulfur dioxide (SO_2) – (a principal cause of acid rain)
- 585,000 pounds of carbon dioxide (CO_2) – (the principal greenhouse gas and the principal product of combustion)
- 150 pounds of coarse particulate matter (PM_{10}) – a principal cause of respiratory illness and an important contributor to smog) (Kats)

In conclusion, the heath and social costs of global warming are continuing to get higher. By cutting these greenhouse gasses, through energy efficient structures, an ever increasing benefit of the utilization of green buildings will arise. Over 20 years the present value of emissions reductions per square foot is $0.53/ft2 from a green school when compared to a conventional school (Assumes.)

Environmental Benefits (Water and Wastewater Reduction)

The direct savings for a building can be overshadowed by the substantial societal benefits of lower pollution and the reduced infrastructure costs of delivering, transporting, and treating wastewater. An EPA report found that nationally there is a gross under-investment in water delivery and treatment systems; this indicates that current water utility rates will have to rise more steeply to secure funds needed for required infrastructure upgrades (Kats.) Also, when there is heavy and extended rainfall, wastewater systems commonly overflow. This causes water pollution, illness, river contamination, and beach closings. Green building water strategies - such as rainwater catchment systems and green roofs - are implemented to provide the benefits of reducing these occurrences. For example in 2005, in Dedham, MA, a school design team, through providing rainwater storage capacity on site, saved the town the cost of enlarging an off site storm water detention facility. The city valued this infrastructure improvement at $400,000.25 (HMFH.) The 30 green schools evaluated in the study in (Appendix A) also achieved significant water savings. When compared to conventional schooling their average water use reductions and savings surmounted 32%. These provide significant statistics to increase the industry's views on the necessity to start thinking more and more "green."

Environmental Benefits (Energy and Maintenance Cost Reduction)

Better design, more energy efficiency equipment, and installation of energy efficiency measures allow typical green schools to use one-third less energy than conventional schools (Appendix A.) By integrating these types of construction into schools it is easy to identify why green buildings generally use more renewable energy. This occurs on and off site from both the purchase of green power and renewable energy credits. Power quality concerns are a significant issue for many businesses, and energy efficiency and renewable energy provide an important way to reduce power quality and reliability costs. Green schools also incorporate design elements such as commissioning and more durable materials that reduce operation and maintenance (O&M) costs. A recent study of the costs and benefits of green buildings for 40 state agencies found that the operations and maintenance benefits of greening California public buildings provide savings worth $8/ft2 over a 20 year period (Kats.) Illustrated in Appendix A, the Canby School in Oregon features exterior surfaces of brick and metal with a baked finish that require virtually no maintenance/painting, as well as a linoleum floor with lower maintenance than conventional flooring (Kats.) It should also be noted that roughly 25% of the solid waste discarded nationally is construction and demolition (C&D) waste, adding up to 130 million tons of waste per year (Lennon.) A study in 1999 concluded that for all (C&D) wastes (including mixed debris), the cost of recycling is less than the cost of disposal by 35% (Skumatz.) This gives extra incentive to initially think green and to continue implementation from an environmental standpoint by recycling throughout the projects duration.

Other Benefits (Background)

Greening school design is much more cost-effective when compared with other available measures to enhance student performance. By providing green schools an increase in staff/student health and learning can be attained. The CEO of the green building council says, "Children's health is disproportionately affected by indoor pollutants, while light and air quality affects their capacity to learn and succeed (Fedrizzi.) The portrayal of a better community image as well as the attraction and retention of teachers also gives more incentive for this type of building methodology. These enhanced learning environments which are also environmentally responsible are continuing to be a focus of AIA awards programs and government advocacy. Reductions in insurance costs pertaining to worker health and safety, property loss prevention, liability loss prevention, and natural disaster preparedness are a few other highlighted items of which a greener school will possess. The following sections of this report intend to illustrate the necessity for these demands and the benefits society will receive from them as a whole.

Other Benefits (Health and Learning)

The health and learning related benefits of green schooling are amongst the major incentives to adopt green building technologies. A Chief Economist, from the Insurance Information Institute, states "most insurers reported a tripling of mold-related claims in 2002 and by early 2003, more than 9000 claims related to mold were pending the nation's courts (Smith.) Therefore the need for improved ventilation and indoor air quality are at the forefront of building green. This will be especially useful to public schooling which sees children in low income families who are 30%-50% more likely to have respiratory problems such as asthma and allergies (Kats). The American Lung Association has found, "American school children miss more than 14 million school days a year because of asthma exacerbated by poor indoor air quality" (Asthma.) Five separate studies evaluating the impact of improved indoor air quality on asthma found, "an average reduction of 38.5% in asthma in buildings with improved air quality" (Carnegie.) This implies that a shift from an unhealthy, conventional school to a healthy school results in a reduction in asthma incidence of 25%. In an average sized new school of 900 students, a 25% reduction in asthma incidence in a healthy school translates into 20 fewer children a year with asthma, with an associated annual cost savings of $33,000.55 (Trends.) Cold and flu reduction are also attributes that a green school will provide. A study by Carnegie Mellon states, "Indoor air quality on colds and flu found an average reduction of 51% in buildings with improved air quality" (Carnegie.) Executive views on reduced student absenteeism and performance can be seen (via Appendix B.) Greening public schools gives opportunities to improve health and educational settings for all students, regardless of income or background.

High performance schools provide hands-on educational opportunities that conventional schools do not. Regarding both full time and summer students, Mike Saxenian, Assistant Head of the School and Chief Financial Officer says that "students have responded with enthusiasm to the school's decision to build green, and faculty are eager to use the new facilities as a laboratory to demonstrate solutions to environmental problems discussed in class (Saxenian). A 3%-5% improvement in test scores can be conservatively expected from high performance schools compared with conventional schools. This is based on an IMF analysis, which also states that a 3-5% improvement in learning and test scores is equivalent to a 1.4% lifetime annual earnings increase. With average annual salary of about $38,000 per year, per individual, this improvement in learning and test scores implies an earnings increase of $532 per year for each graduate from a green school (Kats) These increases in earning, represent the single largest financial benefit from building healthier, more productive learning environments.

Other Benefits (Employment Impacts)

Improved air quality, lighting, and comfort in green school buildings also positively affect teachers. In Appendix B, lies a survey by Turner Construction which states, "3/4 of senior executives interviewed believe that building green improves the school's ability to attract and retain teachers" (Turner.) Building on this premonition, it should be noted that one of the reasons for the adoption of green construction requirements by cities and states is to increase employment. For example, employment benefits are one of the reasons that the New York City Council passed legislation in September 2005 requiring that significant new construction be built green (Kats.) These types of programs allow for an increased amount of employment opportunities to rebuild public infrastructure. A group called the Apollo Alliance is advocating an ambitious national clean investment program. The group's analysis models a $300 billion national investment over a decade in high performance green buildings. By increasing energy efficiency and investing in industries of the future (such as clean technologies), their studies conclude that this would create 3.3 million jobs (The Apollo.) A 2004 report by Black & Veatch on the impact of establishing a minimum energy consumption target for Pennsylvania of 10% from renewables over 20 years was also conducted. This would, compared to business as usual, generate a net increase of $10.1 billion in economic output and increase earnings in state by $2.8 billion and result in 20,000 more jobs (Economic.)

<u>Conclusion</u>

This research has been provided to illustrate the advantages of implementing green design into the current construction sector of school buildings. It was confirmed that greening school design is extremely cost-effective. Green schools cost on average almost 2% more, or $3 more per ft2, than conventional schools (see Appendix A.) However, the increased benefits elsewhere: in energy reduction, improved healthcare, and increased learning capacity seem to outweigh the initial upfront higher cost of 2 %. The analysis of the costs and benefits of 30 green schools and use of conservative and prudent financial assumptions provided a clear and compelling case that greening schools today is extremely cost-effective, and represents a fiscally far better design choice. It also seems as though the industry's standards are still lacking due to the unavailability of attaining concrete information on building green. However, the awareness that is needed for implementation is increasing every day. By reading articles, watching the news, and going online anyone can begin to see initiative for more sustainable

Financial Benefits of Green Schools ($/ft^2)	
Energy	$9
Emissions	$1
Water and Wastewater	$1
Increased Earnings	$49
Asthma Reduction	$3
Cold and Flu Reduction	$5
Teacher Retention	$4
Employment Impact	$2
TOTAL	$74
COST OF GREENING	($3)
NET FINANCIAL BENEFITS	$71

Figure 4. Overall Financial Benefits of Green Schooling (from 30 School Case Study)
Source: Kats

designs. The conclusions that were arrived at, pertaining to the life-cycle benefits of greening schools, have been illustrated above in (Figure 4). Here, you can see that these benefits are about $70 per ft2, which is more than 20 times as high as the initial cost of $3 per ft2. Hopefully this document will encourage others to look further into green building practices and consequently provide designs which support more environmentally friendly school buildings. This is because to achieve full cost savings in the long-run, requires acknowledgement of principles during early integrated design.

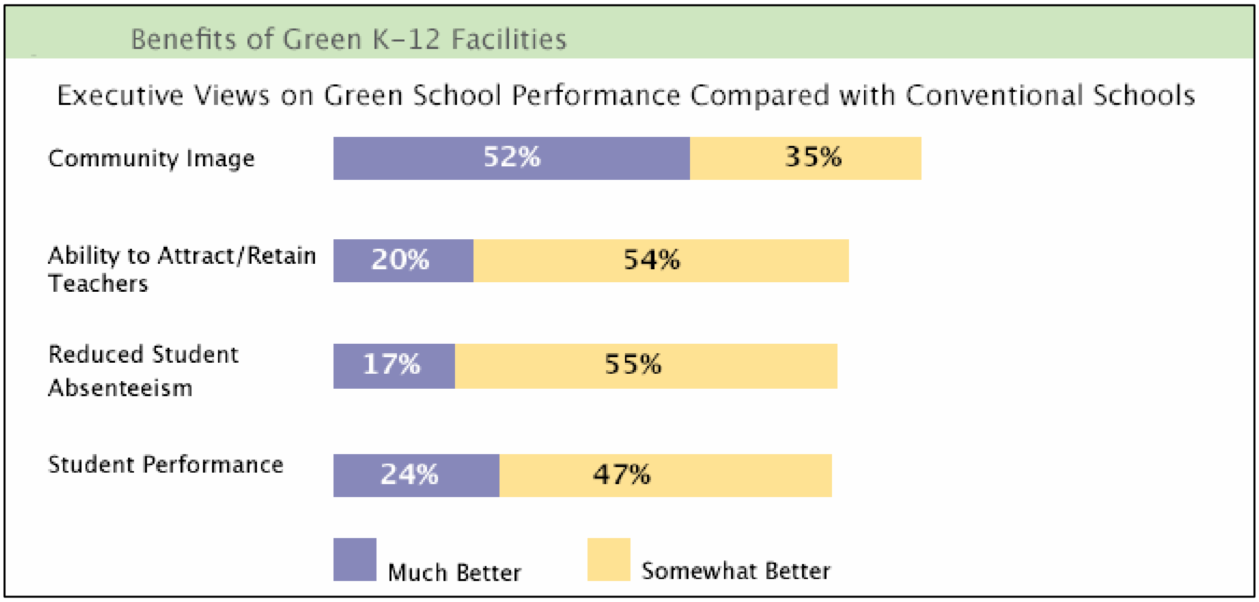
Appendix A

School Buildings Analyzed in This Report[9]

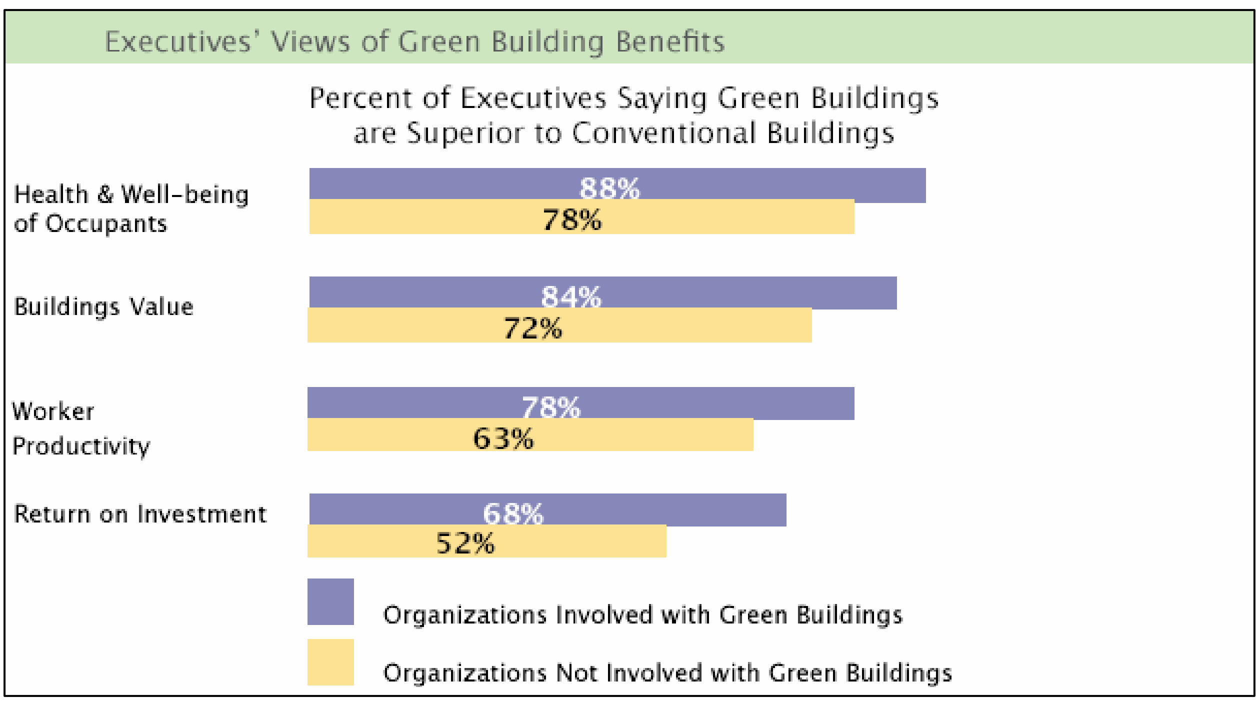
Name	State	Year Completed	2005 MA-CHPS	LEED Score	LEED Level or Equivalent	Cost premium	Energy Savings	Water Savings
Ash Creek Intermediate School	OR	2002			CERTIFIED	0.00%	30%	20%
Ashland High School*	MA	2005	19			1.91%	29%	
Berkshire Hills*	MA	2004	27			3.99%	34%	0%
Blackstone Valley Tech*	MA	2005	27			0.91%	32%	12%
Capuano	MA	2003		26	CERTIFIED	3.60%	41%	
Canby Middle School	OR	2006		40	GOLD	0.00%	47%	30%
Clackamas	OR	2002		33	SILVER	0.30%	38%	20%
Clearview Elementary	PA	2002	49	42	GOLD	1.30%	59%	39%
Crocker Farm School	MA	2001	37			1.07%	32%	62%
C-TEC	OH	2006	35	38	SILVER	0.53%	23%	45%
The Dalles Middle School	OR	2002			SILVER	0.50%	50%	20%
Danvers*	MA	2005	25			3.79%	23%	7%
Dedham*	MA	2006	32			2.89%	29%	78%
Lincoln Heights Elementary School	WA	2006			SILVER		30%	20%
Melrose Middle School	MA	2007	36			1.36%	20%	20%
Model Green School	IL	2004		34	SILVER	2.02%	29%	35%
Newton South High School	MA	2006		32	CERTIFIED	0.99%	30%	20%
Prairie Crossing Charter School	IL	2004		34	SILVER	3.00%	48%	16%
Punahou School	HI	2004		43	GOLD	6.27%	43%	50%
Third Creek Elementary	NC	2002		39	GOLD	1.52%	26%	63%
Twin Valley Elementary	PA	2004	41	35	SILVER	1.50%	49%	42%
Summerfield Elementary School	NJ	2006	42	44	GOLD	0.78%	32%	35%
Washington Middle School	WA	2006		40	GOLD	3.03%	25%	40%
Whitman-Hanson*	MA	2005	35			1.50%	35%	38%
Williamstown Elementary School	MA	2002	37			0.00%	31%	
Willow School Phase 1	NJ	2003		39	GOLD		25%	34%
Woburn High School*	MA	2006	32			3.07%	30%	50%
Woodword Academy Classroom	GA	2002		34	SILVER	0.00%	31%	23%
Woodword Academy Dining	GA	2003		27	CERTIFIED	0.10%	23%	25%
Wrightsville Elementary School	PA	2003		38	SILVER	0.40%	30%	23%
AVERAGE						**1.65%**	**33.4%**	**32.1%**

Analysis: 30 Schools –Case Study on Reduced Energy Consumption
Source: Kats

Appendix B



Survey 1: 2005 Turner Construction Survey of Senior Executives
Source: Turner



Survey 2: 2005 Turner Construction Survey of Senior Executives
Source: Turner

Analysis 1

Green Roof Design

Overview

The purposes of this thesis are intended to illustrate the necessity of building "green" during the construction of school buildings. To further emphasize this viewpoint, the allocation of a green roof will be designed for my thesis building, Baldwin High School. By allowing what was once wasted space, to now become a resemblance of the natural countryside, we can begin to see some of its advantages. The incorporation of a green roof will allow a design that offers multiple environmental benefits while also providing programmable space for outdoor science and environmental studies. The location of this green roof should also be noted because it will be adjacent to each of the newly installed biology classrooms on the third floor of the high school. Hands on experiments such as plant biology and solar access as an energy alternative to fossil fuels will provide an educational element that most other schools do not currently provide. Environmental benefits such as, reductions in storm water runoff, insulation to reduce heating and cooling costs, air filtration, and provisions of a food source for wildlife will also accompany the benefits of an increased aesthetic appeal.

Motivation for Analysis

I decided to conduct this analysis after final completion of my research studies. By becoming more aware of the advantages green school buildings have to offer when compared to conventional school designs; I thought it was pertinent to address these issues within my design topic. Because my thesis building is that of an educational nature, the parallelism intends to provide adequate support for this design strategy's inclusion. When writing the technical report sections for thesis class, I also noticed the incorporation of "nature" within the school building's design documents. This inclusion was important to both the Architect and school board, as they managed to feature designs of both lower and upper courtyards. However, these interior courtyards are based within the center of the school and very little amounts of nature can be witnessed from the gym, natatorium, and recreational parts of the building. The construction of the new gym and natatorium is what has comprised the first two phases of the school's renovation. Being that these areas were the only finished phases by the end of thesis; provided more opportunity to suggest the design of a green roof within these athletic regions. I feel as though the design of a green roof, here, will mirror the internal aesthetics that the gym's sky lighting and third floor classroom windows already provide. In essence, the ability to design a green roof will not only supply a more environmentally friendly structure, but will also tie-in with already existing designs for the acquisition of a more "nature" oriented renovation.

Design Criteria

The influences green roofs have in school design are becoming increasingly more apparent. By implementing these types of construction, schools have a unique opportunity to educate both students and the community to promote the benefits of green roofs. There are two different types of green roofs: extensive and intensive.

Extensive green roofs –range from as little as one to five inches in soil depth and weigh no more than conventional gravel-ballasted roofs. Normally they are light in weight with soil depths ranging from 3" to 7". Due to the shallow soils and the extreme environment on many roofs, plants are typically low growing ground cover that are extremely sun and drought tolerant. Extensive green roofs can be installed over various roof decks; however, a structural engineer should always first inspect the structure to define its weight load limitations. They are primarily built for their environmental benefits, not for access. Waste is further reduced when plants absorb nitrogen and phosphorus as nutrients, eliminating what otherwise would become non-point source pollution.

Figure 5. Extensive Green Roof System Source: (The Calhoun.)

Intensive green roofs –usually require a soil depth of at least one foot in order to create a more traditional roof garden, with large trees, shrubs, and other manicured landscapes. More specifically they are characterized by thick soil depths (8" - 4'), heavy weights and elaborate plantings that include shrubs and trees. Intensive green roofs are installed primarily over concrete roof decks to withstand the weight requirements. Intensive green roofs add considerable load to a structure and require significant maintenance. The roof gardens, however, are designed to be accessible and can be used as outdoor laboratories for schools - a tremendous advantage in urban locations.

Figure 6. Intensive Green Roof System Source: (Garland.)

Typical Characteristics

	Extensive Green Roof	Semi-Intensive Green Roof	Intensive Green Roof
Maintenance	Low	Periodically	High
Irrigation	No	Periodically	Regularly
Plant communities	Moss-Sedum-Herbs and Grasses	Grass-Herbs and Shrubs	Lawn or Perennials, Shrubs and Trees
System build-up height	60 - 200 mm	120 - 250 mm	150 - 400 mm on underground garages > 1000 mm
Weight	60 - 150 kg/m^2 13 -30 lb/sqft	120 - 200 kg/m^2 25 - 40 lb/sqft	180 - 500 kg/m^2 35 - 100 lb/sqft
Costs	Low	Middle	High
Use	"Ecological protection layer"	"Designed Green Roof"	"Park like garden"

Figure 7. Green Roof Types
Source: (International.)

Location of Proposed Design for Baldwin High School

Baldwin High School's renovation project is one that consists of a five-phase sequencing process (as seen in Figure 8). Currently, Baldwin has finished phases one and two of the project.

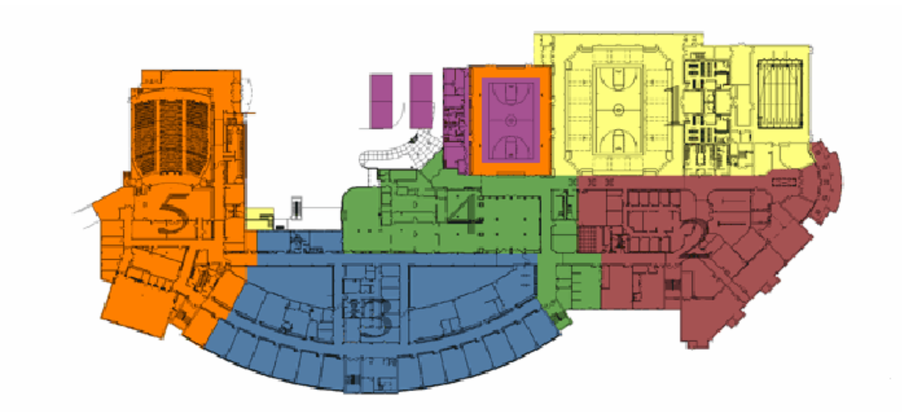


Figure 8. Five Phase Sequencing Process

Phase 1 of the project required demolition of the existing pool and locker room structure and construction of the new gymnasium, natatorium, and locker rooms. Phase 2 focuses primarily on the demolition of a portion of the two-story south wing containing guidance offices and language classrooms. A new athletic entrance and the graphics and communication classrooms have also just finished construction in both regions. Within these five phases the project has been more elaborately broken up into sections ranging from A-H (see Figure 9).

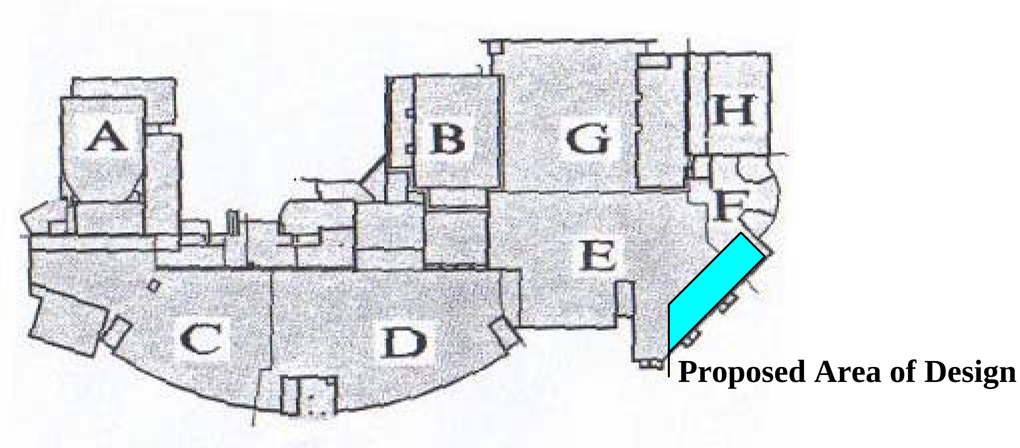
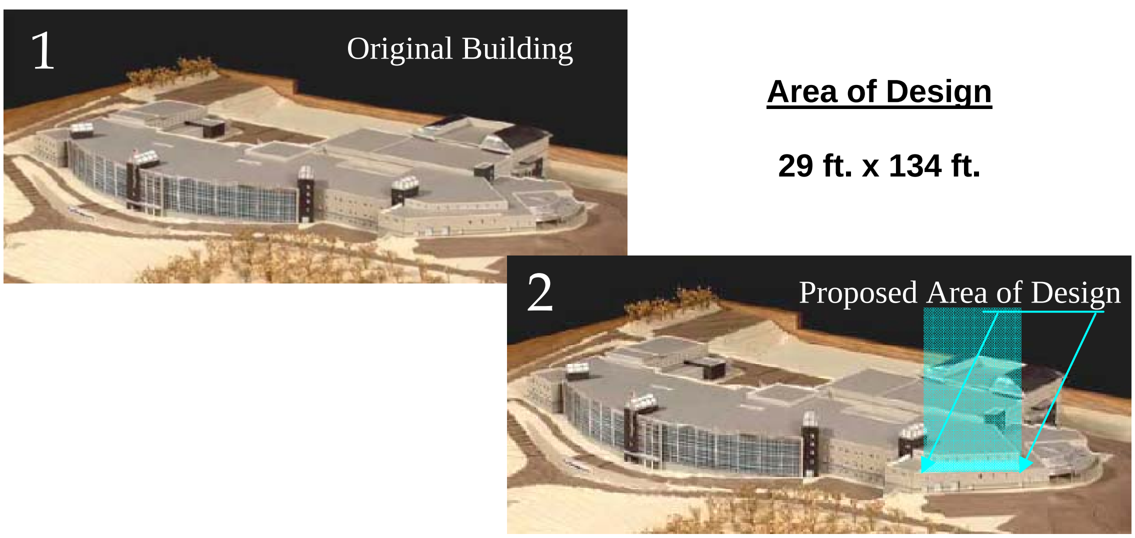


Figure 9. Sections A-H

The inner courtyards of the structure are currently designed to be built between Areas A and B of the diagram. My proposed building design will occur, consequently, on the outer edge of Area E (see Figure 10). Area E proves, what I think is the best balance between the outer extremities of the structure. This design will aid to the "natural" flow and feel of the building, as well as providing an aesthetic appeal for the new athletic entrances.



Area of Design

29 ft. x 134 ft.

Figure 10. Original Design vs. Proposed Design

I feel that this location establishes a vision that embraces sustainable principles and an integrated design approach.

Actual Design

When deciding which green roof system was the best for my intended building. I arrived at the conclusion that a semi-intensive green roof was in order. A semi- intensive roof draws qualities from both intensive and extensive design criteria. Therefore my design entails a deeper growing medium of roughly 1 foot; when compared to an extensive green roof design which incorporates only 3”-7” of soil. The reasoning behind a semi-intensive system was arrived at due to a number of concerns. Firstly, the usage of the green roof is one that calls for a living laboratory for students. This demands a more intensive system due to the fact that more weight will be distributed regarding these characteristics. The notion that moderately sized trees and shrubs will be planted, up to 8’ in height, was also taken into consideration. One would think that the possibilities of a complete extensive system may exist; however, there is no intended pond, large boulders, or large trees to be used. The purposes of this design are mainly for biology class teaching principles and student/teacher visual stimuli. The type of system used resembles the pattern shown above in (Figure 11).

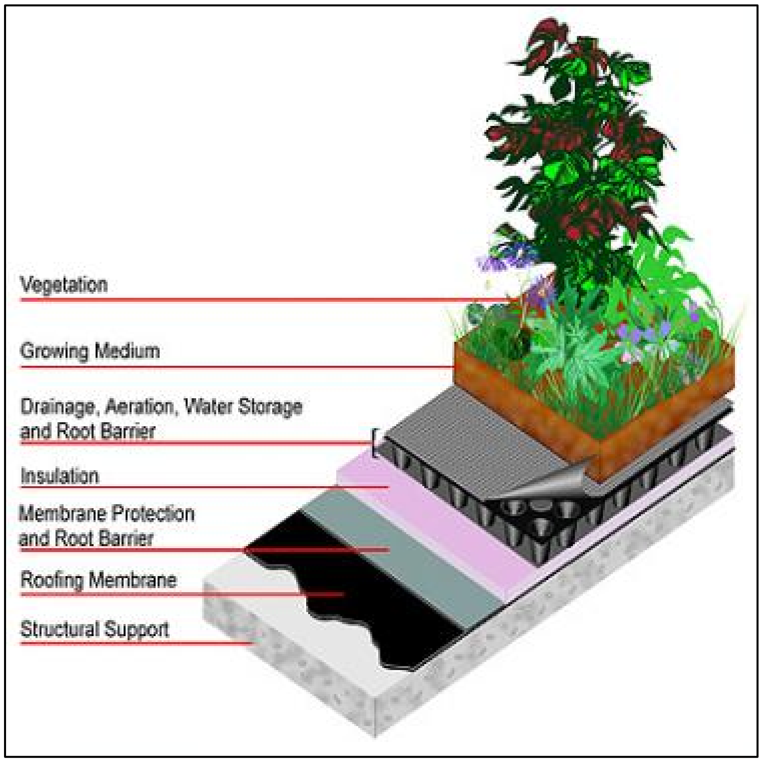


Figure 11. Semi-intensive System Layout

Material Selection (Sequence from Roof to Vegetation Layer)

I chose this green roof system because it provides a light-weight, cost-effective solution for durability and vegetation sustainability. I also feel that this system provides an engineered solution for a lighter weight green roof, which ensures superior resistance to root and moisture penetration of the waterproofing membrane. With that being said, accompanied by the other characteristics of design outlined in the sections above, this system will satisfy my building’s needs. I have designed this roof while regarding the statement, “Green roofs are only as green as the materials from which they are constructed” (Safeguard.)

Structural Support (Roof)

Currently, the renovation and design of Baldwin High School does not call for a green roof in the area that I am proposing that it could be. The typical construction, as seen in (Figure 12), illustrates how the original roof was designed with a 4" normal weight concrete slab on 2"-22 GA composite steel roof deck, resting atop steel W-flange beams. This design was used because the roof was intended to be a low roof with no activity on top of it, other than that of maintenance. However, due to the increased weight that the green roof will provoke, an increased structural support system may be needed.

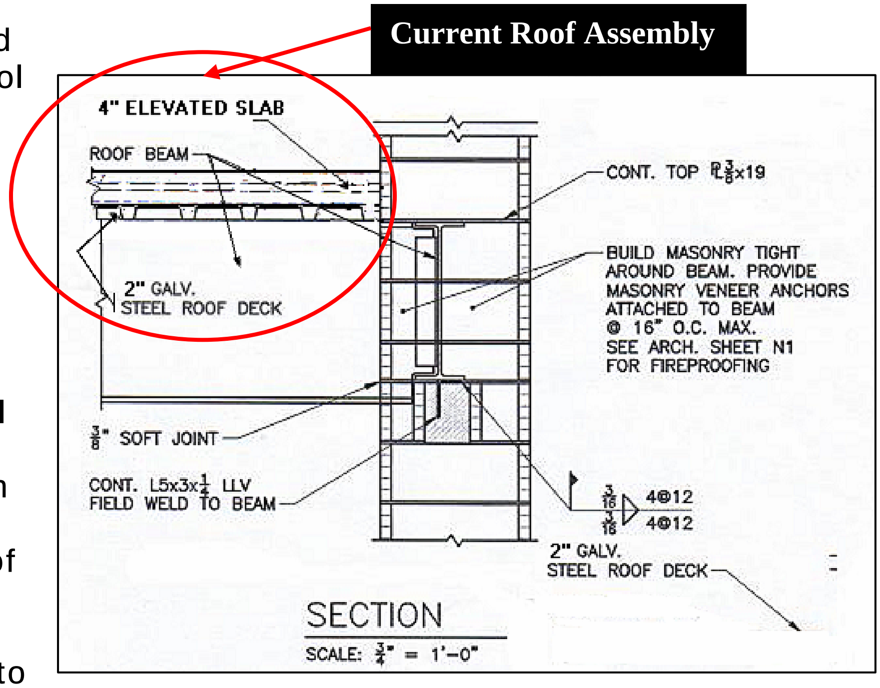


Figure 12. Original Structural Design (3" Galvanized Roof Deck)

Reference to page 41 "Feasibility Study" to see if the building required a redesign of larger beams or columns.

Waterproofing Membrane & Root Barrier

After construction of the new concrete elevated slab we can begin to devise the green roofing's layer system. The first layer, see (Figure 13), shows the placement of the waterproofing membrane and root barrier on top of wood joists. However, Baldwin's design will have the membrane's placement above a concrete elevated slab, which was previously mentioned. The water proofing membranes purpose is to act as the first line of defense for the underlying concrete. My design will utilize a rolled form of material opposed to other designs which might use a liquid or sheet form. After unrolling the membranes, torching the overlaps and seams will be required to substantiate good bonding and to alleviate leaks.

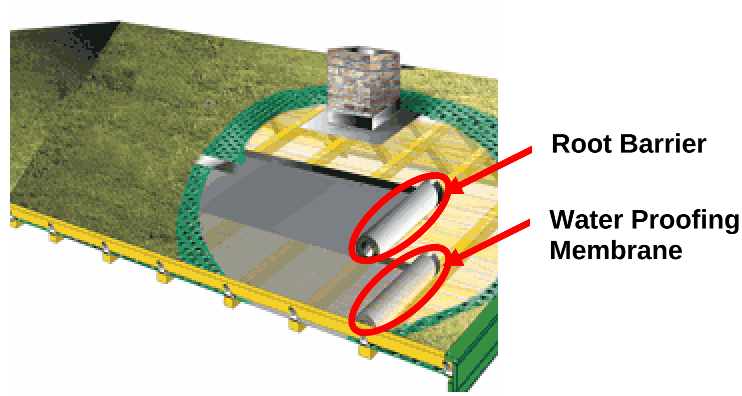


Figure 13. Green Roof Layering System

> Regardless of the type of membrane, ANSI 118.10 has guidelines for waterproof membrane performance. ASTM testing methods sets the guidelines. The membrane must not break when subjected to a load of greater than 170 psi as tested under ASTM C 482. The membranes should also be mold and fungus resistant (The Tile.)

For my design, I decided to use a product called **FAMOGREEN RET CU P5**. This is a high-grade polymeric bitumen fabric with plasto-elastic properties.
It is modified with age stabilizing amorphous polyalphaolefin (APAO). This patented membrane also incorporates a root barrier, secondary drainage layer and waterproofing system all in one. This membrane provides one of the most lightweight and easily installed green roof systems in the industry. Its advanced technology provides superior performance qualities in green roofing systems. When determining the cost and material quantity information it should also be noted that side laps were attributed 4" and end laps a minimum of 6". This effectively diminishes overall coverage by 95 %. For instance, if 100 ft. of space calls for 100 ft. x 0.95 = 105 ft. of material will be needed.

General Specifications

Inlay	Special root resistant polyester with copper film, having a unit weight of 350 g/m²(10.3 oz/yd²).
Bottom Side	Meltable polyethylene film
Top Side	Hydrogel under a special non-woven polyester fleece
Roll Length	7.5 m (24 ft 6 in)
Roll Width	1.0 m (3 ft 3 in)
Roll Weight	51.8 kg (114 lb)
Normal Thickness	5.2 mm (208 mil) *Hydrogel increases thickness
Quantity/pallet	20 rolls/pallet 150 m² (1,614 ft²)
Low Temperature Flex	<-20°C (-4°F)
Heat Stability	>150°C (302°F)
Water Storage Cap.	>3 ltr/m²(>.8 gal/yd²)
Transmissivity of Drainage Layer	>17.5 gal/min/ft.

Figure 14. Waterproofing Membrane Specification Table
Source: Building

Insulation

The insulation I decided to use is **STYROFOAM® Brand R-5 Tongue & Groove Wide Insulation with Clear Film Facing**--48 in. x 96 in. The extruded cell structure, as seen in (Figure 15), has no voids between its cells. This closed cell structure allows for a higher compressive strength and unequaled resistance to water.

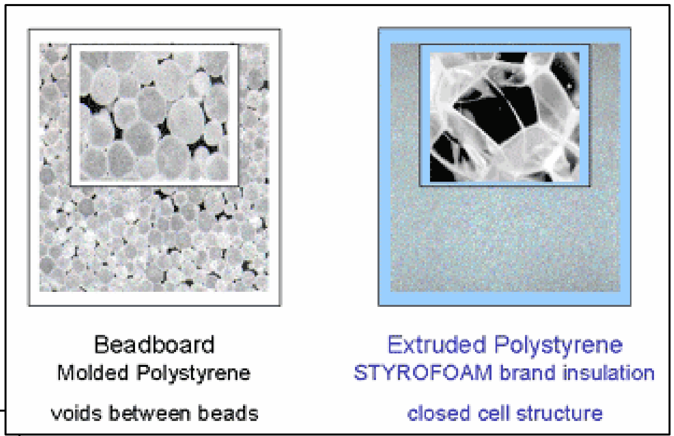
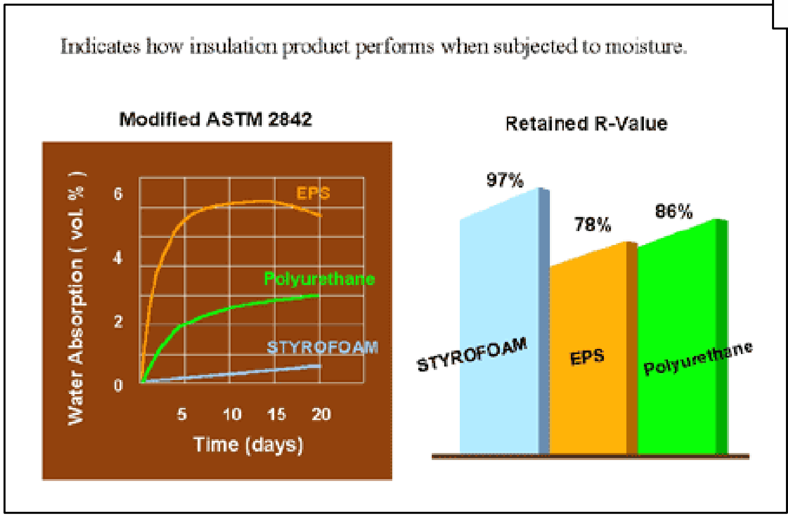


Figure 15. Water Submersion Test Results
Source: Dow



When subjected to moisture it can be seen via (Figure 16), how effective the product is at retaining its R-value.

Figure 16. Water Submersion Test Results
Source: Dow

The R-value is the key statistic regarding the insulation's thermal capacities. Figure 17, is also included to show how the product reacts in a freeze-thaw environment; when compared to other types of insulation. As you can see, Styrofoam continues to maintain a large percentage of its R-value. This is specifically important due to the location of the high school in Western Pennsylvania, which continually sees fluctuating freeze-thaw patterns.

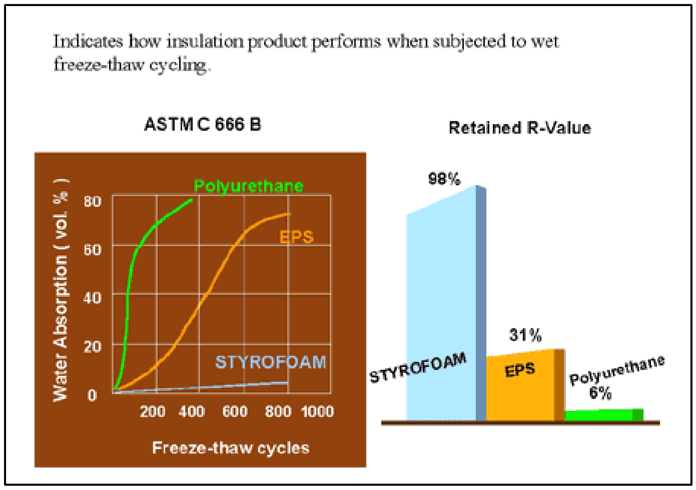


Figure 17. Freeze-Thaw Cycling Test Results
Source: Dow

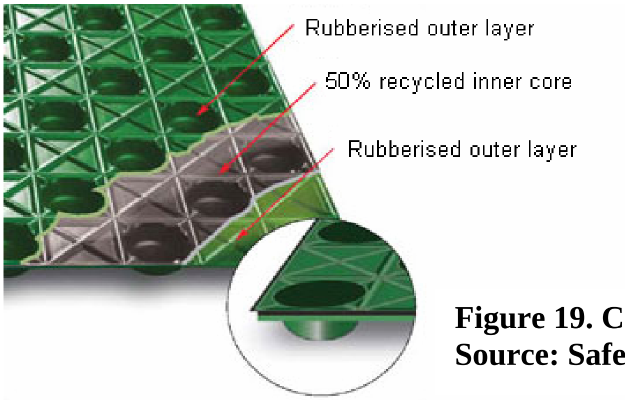
General Specifications

Manufacturer Model No.	1655
Product Name	STYROFOAM® Brand Tongue & Groove Wide Insulation
Width	48 in.
Length	8 ft
Thickness	1 in.
Facing	Plastic film facer
Format	Sheet
R-value	5
Material	Extruded polystyrene (XPS)
Edge Detail	Tongue & groove
Min. Compressive Strength	25 psi

Figure 18. Insulation Specification Table
Source: Ebuild

Drainage Layer

For the drainage membrane of my system, I chose **Oldroyd Green Range “xv20 GreenXtra”**. I decided to use this multi-layered membrane because it consists of three layers (see Figure 19.)



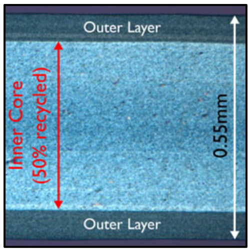


Figure 19. Cross Section of Membrane
Source: Safeguard

Figure 20. Green Roof Drainage Membrane
Source: Safeguard

This multi-layer technology allows recycled material to be used in the inner core; without the loss of performance normally associated with the use of recycled plastic in drainage membranes. The inner core consists of 50% recycled plastic and the rubberized outer layers are manufactured from virgin material. Consequently, this provides several key functions. The first is that it allows a low slip surface for contractors who are working on the roof (see Figure 21). Secondly it improves elasticity of the membrane. Oldroyd Xv 20 Green Xtra is a durable perforated membrane with a 20mm deep stud profile designed specifically for use in green and living roofs. The studs collectively form a rainwater reservoir, providing water for the roof plantings. The 8 mm diameter perforations allow any excess water to drain away.

Figure 21. Rolling out Membrane
Source: Safeguard

The membrane is then blanketed by the Oldroyd Tp filter fleece. This ensures proper root aeration. It also allows a filtrating drainage layer to be laid down before addition of the required soil loading and plantings, as shown in (Figure 22).

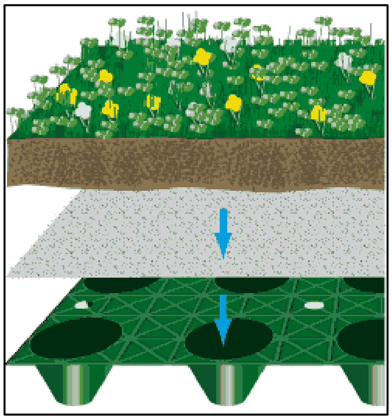


Figure 22. Filter Fleece
Source: Safeguard

General Specifications

Membrane Thickness.	0.8 mm or 0.0315 in
Stud Height	19.2 mm or 0.75 in
Total Height	20 mm or 0.78 in
Drainage Area	36.2 cm²/m² or 0.521 in²/ft²
Color	Green
Weight	0.9 kg/m² or 0.185 lbs/ft²
Vapour Permeability Resistance	1.1x10 12 m²sPa/kg
Tensile Strength (ISO 527)	44MPa or 6.38 psi
Elongation at Break (ISO 527)	1150%
Compressive Strength (SPF VN 2200)	>150kN/m² or 21.76 psi

Figure 23. Drainage Membrane Specification Table
Source: Safeguard

Drainage Layer Attachment to Gutters and Downspouts

Due to the depth of my soil layer, 16”, it was difficult to distinguish exactly what type of irrigation system would be needed. Figure 24, demonstrates how water will typically leave my green roof system. This brings to question, “Exactly how much rainfall will be evaporated due to such a deep growing medium?” The answer is that a very large percentage of rainfall will be evaporated and what is not will be distributed via direct runoff and underflow.

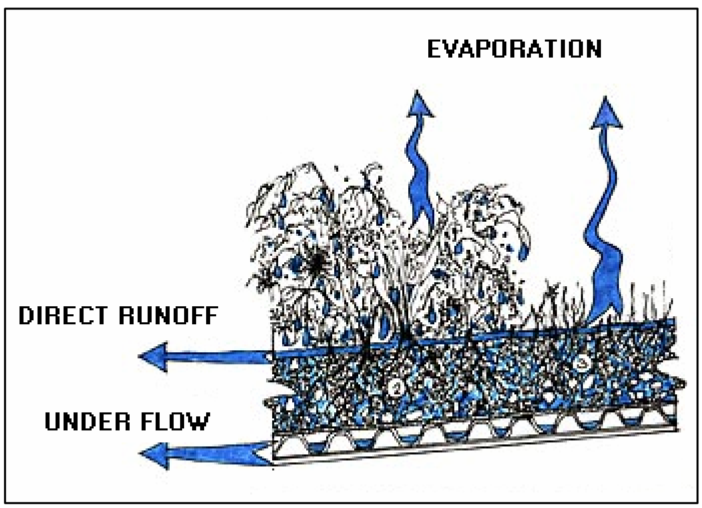


Figure 24. Drainage Pathways
Source: Low Impact

To compensate for the underflow and direct runoff hypothesis, I will be utilizing a 10" perforated pipe around the outside perimeter of the green roof, as seen in (Figure 25). This will tie in with the perforated drainage membrane of the green roof system. Its location can be seen as resting above the insulation layer and below the filter fleece layer.

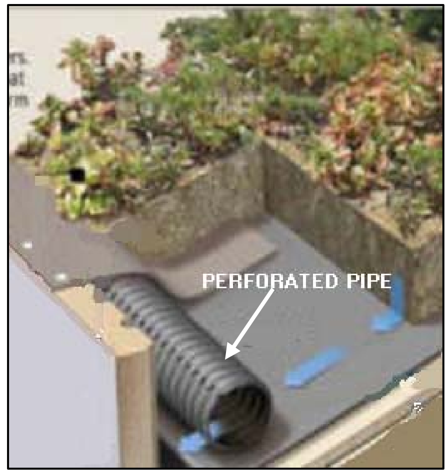


Figure 25. Perforated Pipe between Insulation and Filter Fleece Layers
Source: Carey

Figure 26. Perforated Metal Face Plate & Gutter
Source: International

This construction will then be capped off with a perforated metal face plate (see Figure 26) and allowed to drain in gutters. These gutters will then carry the water to downspouts and will alleviate increased roof loads when heavy rainfall occurs. Drainage outlets will also be provided on the top of the roof. This will be primarily for maintenance concerns, rather than the actual necessity of usage for water distribution.

Growing Medium

The "soil type and depth" of a green roof system is the deciding factor for which types of vegetation to plant. In my design I elected to use **The Sky Garden Intensive Green Roof System**. G-SKY, has developed a lightweight soil mix that will support 95% of all plants on the roof environment for decades. **Roof Soil™** is a lightweight specially-mixed soil with a saturated weight of only 44~50 lbs/ft³ (specific gravity = 0.7~0.8), (see Figure 27). It is almost half the weight of traditional landscape soil or naturally-occurring soil. **Roof Soil™** products are comprised of completely natural 100% organic materials. This provides increased impacts when compared to installation of traditional landscaping soils or naturally occurring soils.

Figure 27. Materials in G-SKY Soil Mixture
Source: G-Sky

This system is designed to use a soil-base that will compliment the plants selected for the green roof. Figure 29, elaborates further on Roof Soil products and their comparison to naturally occurring soils and landscape soils. Figure 28, shows workers who have just laid the filter fleece membrane in preparation to construct the soil layer. The soil depth used in my design was estimated in conjunction with the vegetation layer.

Figure 28. Workers Placing Filter Fleece in Preparation for Soil Layer
Source: G-Sky

Identification of which types of plant life were to be placed, as well as the roof's multi-purpose qualifications, aided in determination of using a 16" soil depth.

General Specifications

Measurement		Unit	Results			
			Roof Soil™	**Roof Soil™ 2**	Naturally-occuring Soil	Landscape Soil
Size Distribution			25mm sieve 80% passed	19mm sieve 80% passed		
Fully-saturated Weight (pF 1.8)		Specific Gravity (lbs/ft^3)	0.79±0.05 (50)	0.7±0.05 (44)	1.6~1.8 (100~112)	1.6~1.8 (100~112)
Thermal Conductivity Coefficient		W/m·K (btu/ft·h·°F)	0.42 (0.24)	0.42 (0.24)	-	-
Three Phase Distribution Ratio	Voids	%	45±5	45±5	See the diagram below	Varies greatly depending on producer
	Liquids	%	35±5	25±5		
	Solids	%	20±5	30±5		
Available Water Capacity (pF 1.8~3.0)		Liters/m^3 (Gallons/yrd^3)	150±30 (30±6)	100±20 (19±4)	Chernozem: 80~140 (16~28) Sandy Loam: 100~150 (19~30)	80~150 (16~30)
Permeability Coefficient		cm/s	1×10^{-2}	1×10^{-4}	1×10^{-2} ~ 1×10^{-5}	1×10^{-2} ~ 1×10^{-5}
pH (H2O)		-	6.0~7.0	6.0~7.0	5.0~6.0	5.5~7.0
Cation Exchange Capacity (CEC)		milliequivalents per 100 grams (me)	20.1	43.7	-	Varies greatly depending on producer

Figure 29. Soil Comparison Chart
Source: G-Sky

Vegetation

Intensive roofs have deep soil profiles that can grow and support lawns, shrubs and trees_Vegetation usually consists of hardy, low-growing, drought-resistant, fire-resistant plants that provide dense cover and are able to withstand heat, cold, and high winds. Varieties commonly used include succulents such as sedum and delosperma. During dry periods, these plants droop but do not die back; when it rains, they quickly revive and absorb large amounts of water (Low Impact). Within my design I used these sedum plants as well as grasses, grand plants and herbs. I also used perennials of small height and medium sized bushes and shrubs. I also incorporated a few low-medium height trees. I used the table, in Figure 30, to help receive a broader understanding of my selection options and what the required depths of soil were.

	Sedum Plants	Grand Plants	Grasses and Ground Covers	Mid-sized Perennials & Herbs	Tall Perennials & Small Shrubs	Small Trees & Tall Shrubs	Mid-sized Trees
Plant Height	10~100mm (3/8~4")	100~250mm (4~10")	200~400mm (8~16")	300~600mm (12~24")	600~1200mm (24~48")	1200~2000mm (48~79")	2000~4000mm (79~158")
Required Roof Soil Depth	30mm (1-3/16")	100mm (4")	150mm (6")	200mm (8")	250mm (10")	300mm (12")	400mm (16")
Required Drainage Layer	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Figure 30. Plant Selection Guide and Soil Depth Chart
Source: G-Sky

Sedum Plants Used

Selection 1

Mexican Sedum Sedum mexicanum		USDA Zone 5	Bright green sedum with yellow flowers in the spring. A fast grower compared to other sedums. Slightly frost-tender but always rebounds.

Figure 31. Mexican Sedum

Selection 2

Coral Carpet Sedum album 'Coral Carpet'		USDA Zone 3	Dark Green in non-drought conditions and bright red in drought conditions. An extremely hardy and versatile plant.

Figure 32. Coral Carpet

Grand Plants Used

Selection 1

Moss Pinks Phlox subulata 'Pink'		USDA Zones 2 to 9	Phlox forms a dense mat of moss-like foliage that is covered in spring with masses of flowers in pink, purple, or white depending on cultivar. Cut about halfway to ground after flowering to induce vigorous growth.

Figure 33. Moss Pinks

Selection 2

Mother of Thyme Thymus serphyllum		USDA Zones 4 to 8	Of the several types of thyme available, this is the most common and best suited for Green Roofs. It covers extremely well, lets off a pleasant aroma, is extremely drought tolerant and is very low maintenance.

Figure 34. Mother of Thyme

Grasses and Ground Covers Used

Selection

Zoysia Grass Zoysia japonica		USDA Zones 7 to 11

Figure 35. Zoysia Grass

Perennials, Herbs and Shrubs Used

Selection 1

Montauk Daisy Chrysanthemum nipponicum		USDA Zones 5 to 8

Figure 36. Montauk Daisy

Selection 2

Spanish Lavender Lavandula stoechas		USDA Zones 6 to 10

Figure 37. Spanish Lavender

Selection 3

Burning Bush Euonymus alatus		USDA Zones 4 to 8

Figure 38. Burning Bush

Low-Medium Height Trees

Selection 1

Wax-Leaf Privet Ligustrum japonicum		USDA Zones 8 to 10

Figure 39. Wax-Leaf Privet

Selection 2

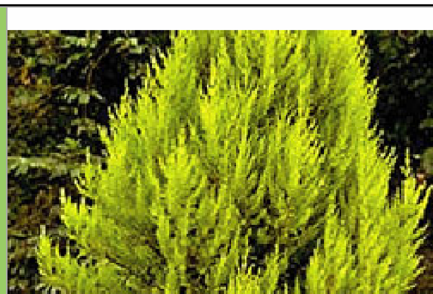
Goldcrest Cupressus macrocarpa		USDA Zones 7 to 10	Loves to be pruned keeping it the same size for most of its life. If left to grown naturally, it can grow to very high heights and therefore pruning is necessary. Extremely hardy and attractive. Conifers of all types are perfectly suited for Green Roofs.

Figure 40. Goldcrest

Complete Design

Green Roof Layers (Schematic 1)

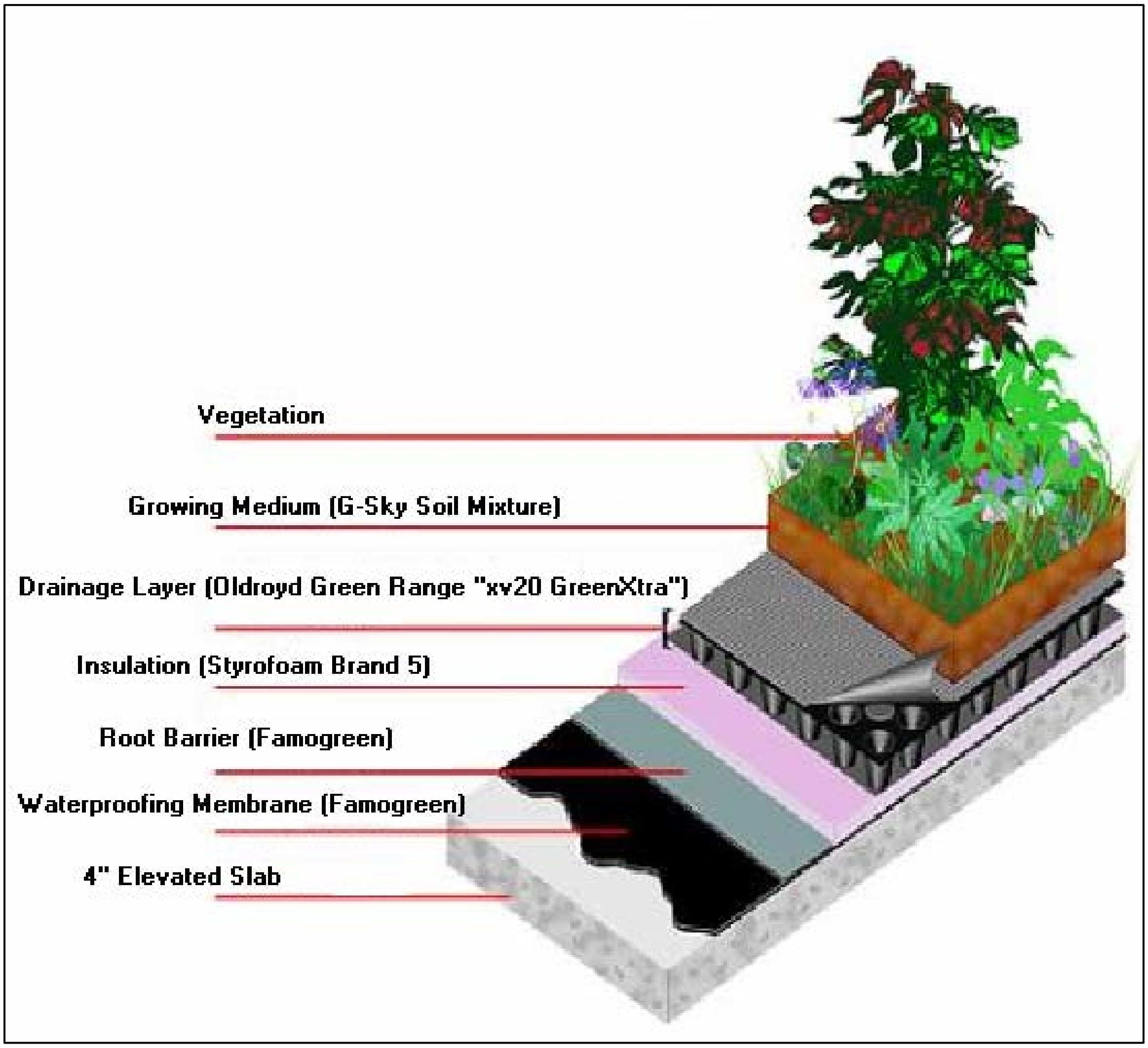


Figure 41. Complete Green Roof System Design

Green Roof Layers (Schematic 2)

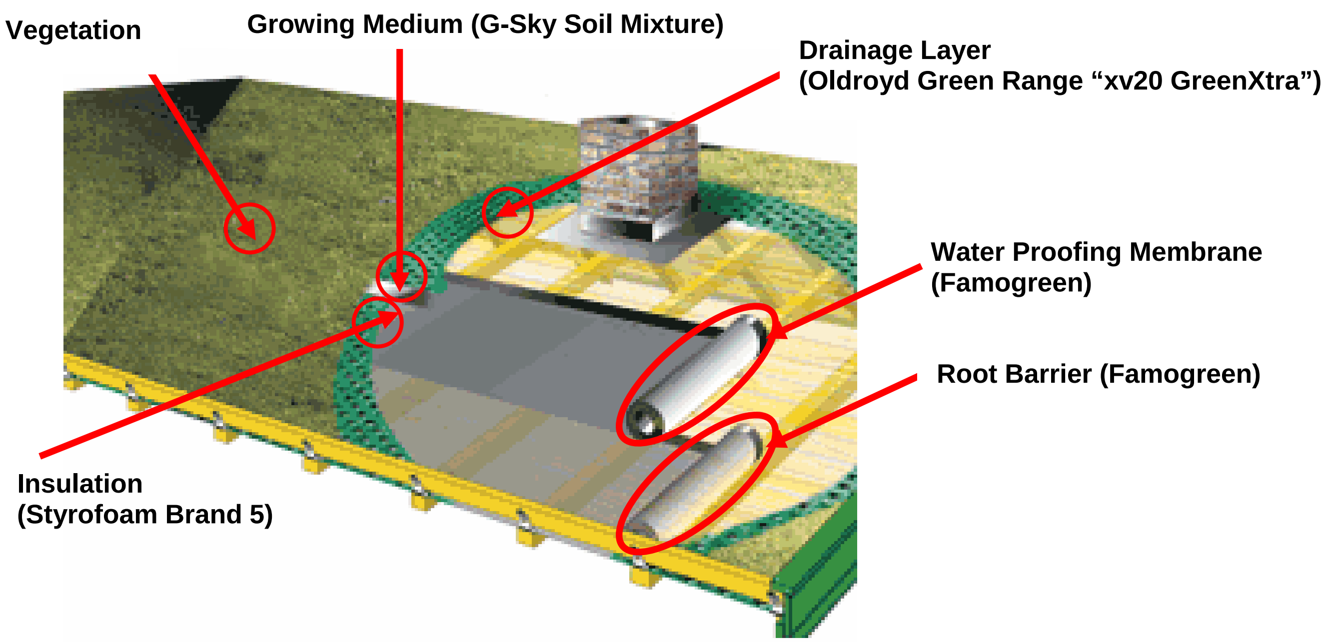


Figure 42. Complete Green Roof System Design

Assume:
1. Green Roof will be on a flat non-pitched surface.
2. Vegetation layer will be comprised of its own unique design.

Complete Green Roof Design (Quantitative)

Structural System	4” Elevated Slab	thickness = 4”
Waterproofing Membrane	Famogreen	thickness = 0.1”
Root Barrier	Famogreen	thickness = 0.1”
Insulation Layer	Styrofoam Brand 5	thickness = 1”
Drainage Layer	Oldroyd Green Range	thickness = 0.75”
Growing Medium	G-Sky Soil Mixture	thickness = 16”
Vegetation	Mixed	

Total System Thickness	22”
Total Area	3871 Ft^2
Total Area of Openings	320 Ft^2
Total Usable Area	3551 Ft^2
Cost per SF	$35.00
Initial Upfront Cost	$124,285.00
Expected Lifespan	40 years
Annual Maintenance	3 years
Irrigation	Perforated Exterior Pipe/Gutter/Downspout

Perimeter railings were not included in design or in cost estimates

Complete Green Roof Design (Quantitative)

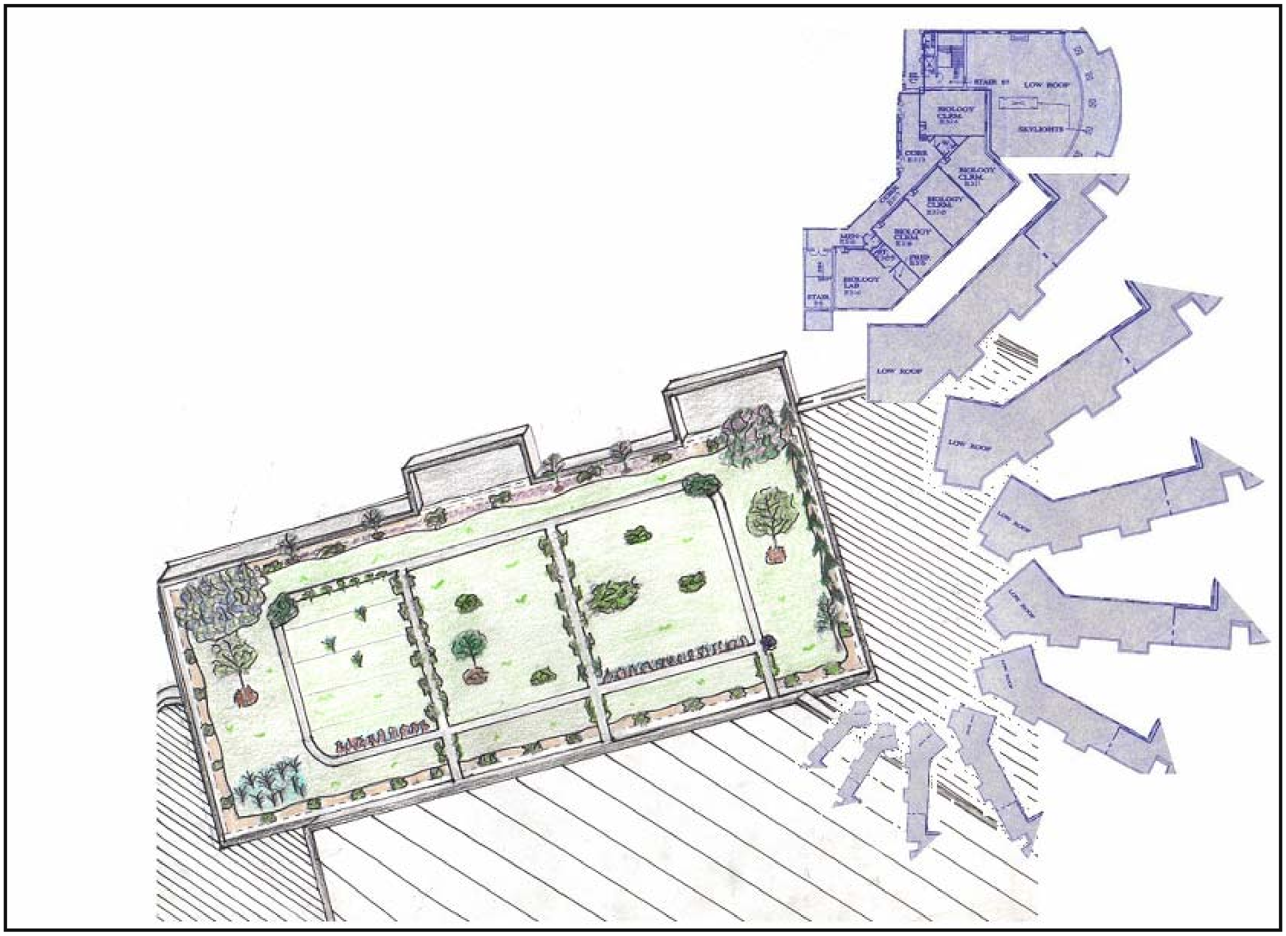


Figure 44. Design Sketch of New Green Roof

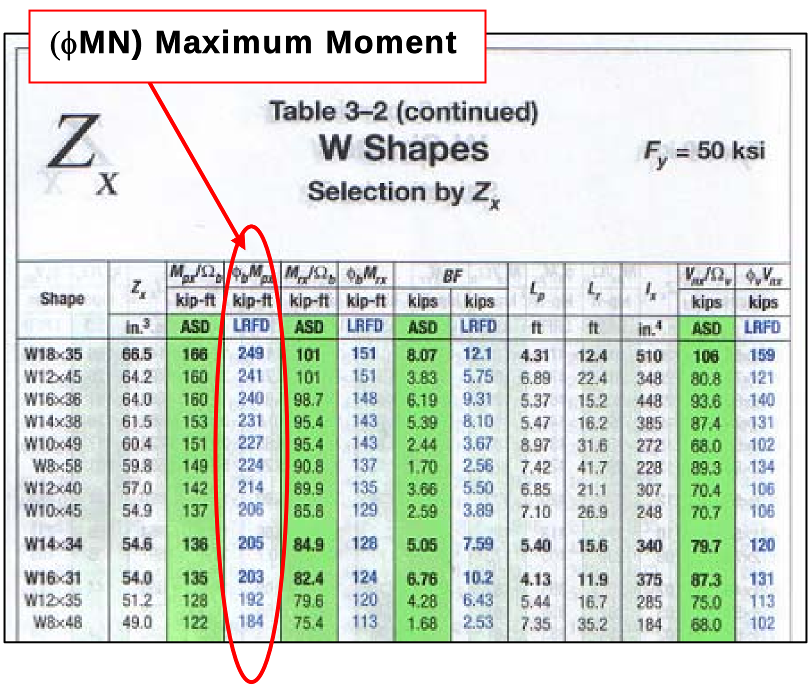
Feasibility Study

Structural Redesign vs. Initial Design

Intensive green roofs require a deep growing medium to allow for the use of trees and shrubs. Therefore the depth of this growing medium incurs extra loading requirements within the loading structure. Taking these occurrences into consideration required further examination of the existing structural plan.

I did this by separating the beam framing plan into sections. The 5 various sections are illustrated in (Figure 45.) I did this for note keeping reasons, so that I could easily reference an insufficient beam, if one so existed after my analysis.

Figure 45. Structural Beam Framing Areas
Source: ASTM



(ϕMN) Maximum Moment

Table 3–2 (continued)
W Shapes
Selection by Z_x
F_y = 50 ksi

Shape	Z_x	M_{px}/Ω_b	$\phi_b M_{px}$	M_{rx}/Ω_b	$\phi_b M_{rx}$	BF	BF	L_p	L_r	I_x	V_{nx}/Ω_v	$\phi_v V_{nx}$
		kip-ft	kip-ft	kip-ft	kip-ft	kips	kips				kips	kips
	in.^{3}	ASD	LRFD	ASD	LRFD	ASD	LRFD	ft	ft	in.^{4}	ASD	LRFD
W18×35	66.5	166	249	101	151	8.07	12.1	4.31	12.4	510	106	159
W12×45	64.2	160	241	101	151	3.83	5.75	6.89	22.4	348	80.8	121
W16×36	64.0	160	240	98.7	148	6.19	9.31	5.37	15.2	448	93.6	140
W14×38	61.5	153	231	95.4	143	5.39	8.10	5.47	16.2	385	87.4	131
W10×49	60.4	151	227	95.4	143	2.44	3.67	8.97	31.6	272	68.0	102
W8×58	59.8	149	224	90.8	137	1.70	2.56	7.42	41.7	228	89.3	134
W12×40	57.0	142	214	89.9	135	3.66	5.50	6.85	21.1	307	70.4	106
W10×45	54.9	137	206	85.8	129	2.59	3.89	7.10	26.9	248	70.7	106
W14×34	54.6	136	205	84.9	128	5.05	7.59	5.40	15.6	340	79.7	120
W16×31	54.0	135	203	82.4	124	6.76	10.2	4.13	11.9	375	87.3	131
W12×35	51.2	128	192	79.6	120	4.28	6.43	5.44	16.7	285	75.0	113
W8×48	49.0	122	184	75.4	113	1.68	2.53	7.35	35.2	184	68.0	102

Figure 46 ASTM (ϕMN) maximum allowable load
Source: ASTM

I then used the original design and determined the maximum allowable Moment (ϕMN) from the ASTM manual for Wide-Flange beams (see Figure 46.) By working backwards and using the equation W(l)^2/8=ϕMN, in regard to uniformly distributed loads on simple beams, I was able to calculate the load in terms of (klf). I then divided this load by the span width of that individual section. This gave me my intended answer for the analysis in (psf) that of which I used for purposes of a reference "maximum load allowable" by each beam. This process can be seen via (Figure 47).

EXAMPLE CALCULATION (Max. Dist. Weight)
Beam = W 16 x 26
Length = 29 ft.
Span = 7 ft.
ASTM Table (ϕMN) = 166 ft-kip
W = ?
Max. Distributed Load. = ?

1.) $166 \text{ ft-kip} = \frac{W(29 \text{ ft.})^2}{8}$

W = 1,579 klf

2.) 1,579 klf / 7 ft. o.c. = 225.6 psf.

3.) **225.6 psf**. = maximum allowable load before failure and redesign must occur.

Figure 47. Example (Max. Allowable Load Calculation)
Source: ASTM

I compared these maximum allowable loads to the new load encountered from my green design (see Figures 48 & 49). The study concluded that the original plans had *significant flexibility* pertaining to the allowance of an increased roof load. I feel that the plans were initially under designed for the original loading combinations. By documenting and illustrating the increased loading, due to the new roof, it was seen that in every beam case the design was still less than the maximum allowed. This proves that a redesign of the beam sizes will not be needed for implementation of a new green roof design.

CALCULATION (New Roof Max. Load (psf))
Area = 29' x 144' = 3871 ft.^2
Green Roof Load

	Roof Dead Load	= 60 psf.
new	Green Roof Dead Load Increase	= 20 psf
	Mechanical	= 4 psf
	Roof Live Load	= 30 psf
new	Green Roof Live Load Increase	= 30 psf

*Assume snow load is accounted for in live load quantity.
*Assume Mechanical Units will remain on roof, however distribution may need to be reconfigured.

Total Force = 1.2 (Dead Load) + 1.6 (Live Load)
= 1.2 (84 psf) + 1.6 (60 psf) = **162.4 psf**

1.) Is load less than the maximum allowable load for any of the beams?
2.) If so, no redesign is necessary.
3.) Substitute into *Beam Calculation Worksheet* to find out.
.

Figure 48. Example (New Roof Load Calculation)
Source: ASTM

Structral Beam Analysis
Detailed Worksheet

Project Name: Balwin High School
Dates of Construction: September 2005 - February 2006

BEAM	SIZE	ΦMN (kip-ft)	MAX. LOAD (psf)	>	DESIGN LOAD (psf)	REDESIGN REQD.
AREA 1 (7FT O.C.)			SPAN = 29'			
A1-B1	W 16 X 31	203	275.8	>	162.4	NO
A2-B2	W 16 X 26	166	225.6	>	162.4	NO
A3-B3	W 16 X 26	166	225.6	>	162.4	NO
A4-B4	W 16 X 26	166	225.6	>	162.4	NO
AREA 2 (8FT O.C.)			SPAN = 29'			
A4-B4	W 16 X 26	166	197.4	>	162.4	NO
A5-B5	W 16 X 31	203	241.4	>	162.4	NO
A6-B6	W 16 X 31	203	241.4	>	162.4	NO
A7-B7	W 16 X 31	203	241.4	>	162.4	NO
A8-B8	W 16 X 31	203	241.4	>	162.4	NO
AREA 3 (8FT O.C.)			SPAN = 29'			
A8-B8	W 16 X 31	203	241.4	>	162.4	NO
A9-B9	W 16 X 26	166	197.4	>	162.4	NO
A10-B10	W 16 X 26	166	197.4	>	162.4	NO
A11-B11	W 16 X 26	166	197.4	>	162.4	NO
A12-B12	W 16 X 31	203	241.4	>	162.4	NO
AREA 4 (8FT O.C.)			SPAN = 29'			
A12-B12	W 16 X 31	203	241.4	>	162.4	NO
A13-B13	W 16 X 31	203	241.4	>	162.4	NO
A14-B14	W 16 X 31	203	241.4	>	162.4	NO
A15-B15	W 16 X 26	166	197.4	>	162.4	NO
AREA 5 (7.5FT O.C.)			SPAN = 29'			
A15-B15	W 16 X 26	166	210.5	>	162.4	NO
A16-B16	W 16 X 26	166	210.5	>	162.4	NO
A17-B17	W 16 X 26	166	210.5	>	162.4	NO

Analysis: NO redesign will be required for the already installed W-flange beam frame system.

Figure 49. Green Roof Area –Structural Beam Analysis

Upfront Cost Comparison

Understanding the benefits of green roofs and green schooling in general, will benefit the application of these types of construction. It should be recognized that a green roofing system has the potential to double the roof's lifespan. Green roofs also provide a reduction in summer cooling needs, reductions in heat loss during winter, increased sound insulation, reduced school absences and stress, plus visual amenities and teaching opportunities. However, the construction industry is one that operates on low-bidding and cost cutting. This hinders the ability for consumers to see the long-term possibilities of which, going green, suggests. With this being said, I now intend to illustrate one of the largest concerns with the integration of a green roof, cost.

Cost Comparison
Detailed Worksheet

Project Name: Balwin High School
Dates of Construction: September 2005 - February 2006

B1010 Floor Construction

Steel Joists, Beams & Slab on Columns

ACTUAL ROOF	BAY SIZE (FT.)	DEPTH (IN.)	TOTAL LOAD (PSF)	COST PER S.F. MAT.	COST PER S.F. INST.	COST PER S.F. TOTAL
Actual Roof Design	29 x 27.5 (AVG.)	16	94	~	~	~
Means Data Used	30x30	29	110	$6.80	$4.37	$11.17
Misc Materials	~	~	~	~	~	$3.00
						$14.17
		Total = ($14.17)x(3871 SF) = $54852.00				$54852.00

Roof Returns

7500.002	Quantity (SF.)	COST PER S.F. Sub UNIT	COST PER S.F. TOTAL
Roof Returns	440	$8.00	$3,520.00

Gravel Stop

7500.01	Quantity (LF.)	COST PER L.F. Sub UNIT	COST PER L.F. TOTAL
Gravel Stop	148	$15.00	$2,220.00

Copings

7500.011	Quantity (LF.)	COST PER L.F. Sub UNIT	COST PER L.F. TOTAL
Copings	15	$25.00	$375.00

Remove & Replace Copings

7500.012	Quantity (LF.)	COST PER S.F. Sub UNIT	COST PER S.F. TOTAL
Remove & Replace	18	$50.00	$400.00

Total Summed Roof Cost =
= $54852.00 + $3520.00 + $2220.00 + $375.00 +400.00
= $61367.00

Total Cost = $61367.00

Figure 50. Actual Roof Cost Estimate, also see Figure 50

This cost analysis has been devised for the purposes of demonstration, (see Figure 50). It intends to illustrate the increased cost of my green roof system as an addition to Baldwin's high school. Currently, there are few estimating books available for the purposes of straight forward –green building product unit price comparison. However, green roofing systems are estimated for various assembly types and project descriptions. These costs range from \$15-\$60/SF and include estimation of all membrane and plant costs. My roof design has been designed to include moderately priced materials and a large amount of open space. This reduces cost somewhat, but green systems are designed for life-cycle, environmental, health, and aesthetic reasons. Therefore the increased cost, which was about twice as much as what the original design cost was, –was somewhat expected, (see Figure 51).

Within this upfront cost comparison I conservatively assumed that the price of my system lied within a lower/middle range of green flooring systems, around \$35/SF. I also subtracted portions of the roof which were allocated for rooftop units or ventilation devices –from the total area.

I then concluded that my specific green roof design would induce an increase in upfront-cost indefinitely. When the cost of my design, totaling \$124,285.00, was compared to the actual

CALCULATION (Upfront-Cost Comparison)

Area of Green Roof Placement
(29' x 134') – (320' *roof openings*) = 3551 ft^2

Actual Roof Design (See Figure 47)
Steel Joists, Beams, and Slab on Concrete
1. (Cost per SF) x (Area SF) = Cost on Project
2. (\$14.17) x (3871 ft^2) = \$54,852.00

Roof Returns = \$3,520.00
Gravel stop = \$2,220.00
Copings = \$375.00
Remove & Replace Coping = \$400.00
Total Cost = \$61,367.00

Green Roof Design
1. (Cost per SF) x (Area SF) = Cost on Project
2. (\$35.00) x (3551 ft^2) = \$124,285.00

Increased Upfront-Cost
= (Designed Green Roof Cost) – (Actual Roof Cost)
= (\$124,285.00) – (\$61,387.00)
= \$62,918.00

\$62,918.00 = (Increased Upfront-Cost)

202% = (Increased Upfront-Cost %)

Cost Relative to Total Project Cost
= (Designed Green Roof Cost) / (Actual Project Cost)
= (\$124,285.00) / (\$64,000,000.00)
= 0.2%

0.2% = (Total % of Renovation Cost)

0.1% = (Increased Renovation Cost)

Figure 51. Upfront Cost Comparison

design's estimate, which was $61,367.00; it was seen that if implemented my design would cost about "202%" on an upfront cost basis. One could argue that the life span of a green roof, being twice that of a regular roof, would even out the increased upfront cost dilemma. However, in most cases school buildings do not have a 40 year life span and will never witness the cost benefits of providing this type of roofing system.

This cost comparison has rectified some of the discouragements for "going green" by illustrating its upfront-cost disadvantages. My proposed green roof system nullified the hopes of providing a cost-effective means of design. However, when regarding the new design as a percentage of the $64 million renovation, results showed that this increase was only 0.2 %. More importantly, the increased cost to the project, regarding the actual roof cost, was that of only 0.1 %. This shows that on a large scale project like Baldwin, the risks you take to implement green systems don't seem to be that risky at all. Therefore the conclusions which were arrived at highlighted an even bigger question concerning the construction industry. This being, when will the American economy and the construction industry as a whole –start basing their design principles on the environment and health –instead of specifications and cost?

Conclusion

Upon completion of the research portion of this thesis, the search for a design which could produce a more "green" type of building construction was sought after. Consequently, the design of my green roof, opposed to that of Baldwin's traditional roofing system, demonstrated a multitude of learning experiences. Its location within the building –relative to the schools entirety, and the utilization of what was once wasted space; were driving forces behind this building's chosen area of reconstruction.

The motivation to produce and design my own system of green construction has allowed me to emphasize the benefits of a more environmentally friendly way of making buildings. The benefits of a green roof include a lower cooling load, reduced roof temperature, and a potentially longer roof membrane life. However, roofing costs can vary considerably depending on the type of roof and the area that is to be constructed. Therefore the materials that were chosen in my system resembled ones that take consideration for both cost and sustainability. It was concluded then, that the components within a green roof can actually benefit the environment just as much as the entire system itself can.

It was also calculated that the standard (roof live load design increase) was not substantial enough to produce a structural redesign. I did this by determining that the maximum allowable load added by the green roof was not large enough to induce failure in any of the beam members in question. I have attributed these circumstances to the substantial over design of the members, as well as the green roof being a semi-intensive system with low vegetation height. This adds minimal weight to the building, while also satisfying environmental, educational, and visual needs.

It was hard to give a concrete definition of the exact benefits my system will provide from an energy-cost basis. This is due to the fact that it is an original construction with no way of comparing its energy cost savings as a whole system. The process that would entail such a study would require implementation in design, construction, and then documentation over the roof's entire life-cycle. However, an upfront cost analysis was compared to the original roof's upfront cost. My thesis proves that this increase in cost, nearly doubling (202%) what the original design cost was, is fairly minimal when taking into account the green design's contribution (0.2%) to the overall renovation's $64 million budget.

This concludes that the design of my green roof was twice as much as what the original roof cost would have been. Although this figure initially seemed high, further study has proven that it is around the industry average for a green roof cost increase. This figure also brings to debate the discrepancy regarding implementation of green building processes and their benefits to disadvantages comparison.

The construction industry is currently on a standstill of how prolific the design of "green" into buildings actually is. The industry, however, is continually receiving education on the environmental, health, and life-cycle benefits that these types of systems can provide. The increased advantages that a green roof has to offer regarding these characteristics, seems the better choice when compared to traditional roof design. Because the design for my green roof occurs within a school building, these incentives become increasingly more knowledgeable and important. With the continual education of how green building systems work and the initiative to make a difference, there seems to be little debate as to "Why not implement?" The only discrepancy, however, is the cost aspect of this implementation. Currently owners, designers, and contractors are trying to compromise on the cost aspect of supplying, designing, and implementing these types of systems. Hopefully, as a progressive move to the future, this uneven balance of cost vs. the environment will weigh out a little better for the environment. This is because cost savings and low-bidding only benefit some, whereas environmental and health considerations will benefit all.

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Analysis 2

Alternate Window Selection

Overview

The idea behind this analysis is to illustrate the selection of an alternative material for my building, Baldwin High School. More specifically, how the selection of this material will produce greater environmental and health benefits for the school building, at relatively the same cost as the original material selected. To do this I will use an item found within the renovation design's estimate package. The item in question, windows, will serve as the basis for an alternative material selection. Regarding the estimate package as a whole, I felt that the windows selected for design were selected primarily on a specification and low cost method. This analysis will demonstrate how the selection of a more "green" oriented building product can be purchased for the same cost as the standard selections which were used in my actual project's design. I will set out to prove that unlike my green roof's increased cost of execution, not all environmentally friendly building products induce such an increase. I will illustrate this methodology by performing a cost comparison analysis of the proposed window selection and my alternative selection.

Motivation for Analysis

I decided to carry out this analysis after conducting research and establishing the principles needed for my green roof design. Upon completion of that design, I noticed the same trend which currently discourages implementation of green building practices in today's construction industry. This being the trend of an increased upfront cost associated with little knowledge about other incentives for acquiring a "green design" type of methodology. This led me to evaluate certain materials in my own building which were designed solely for the purposes of specification requirements and low cost purchasing. Within the building estimate I arrived at a few items which could possibly have better "green" alternative selections. More importantly, selections which can be applied to the original design and ultimately induce a more environmentally friendly learning environment for my school building, regarding the same relative cost basis.

Student Performance and the Indoor Environment

Alongside the benefits that increased lighting, ventilation, and air quality have for student learning lies a building material "windows" which also attributes to their educational success. In the "Research" section of my thesis you can find additional environmental and learning objectives that these benefits also adhere to. These objectives give implications to how the physical conditions of a school indefinitely affect a student's learning rate. A study by the California Energy Commission found that "various window characteristics of classrooms have as much explanatory power in explaining variation in student performance as more traditional educational metrics such as teacher characteristics, number of computers, or attendance rates (California.) This same study also validated previous research by finding a statistical correlation between the amount of daylight in elementary school classrooms and the performance of students on standardized math and reading tests. Although these findings were researched and conducted for elementary school purposes, it can be conservatively assumed that the conclusions will also be of importance to other educational facilities. More specifically, the conclusions made from this report will prove the importance of an alternative material selection for the "windows" item of the project's estimate. Further documentation as to the findings of this 105 page technical report can be seen (via Figure 52.)

Analysis Findings from Technical Document

1. 0verall, elementary school students in classrooms with the most daylight showed a 21 % improvement in learning rates compared to students in classrooms with the least daylight

2. A grade level analysis found that the day lighting effect does not vary by grade

3. An absenteeism analysis found that physical classroom characteristics (day lighting, operable windows, air conditioning, portable classrooms) are not associated with variations in student absenteeism. This seems to contradict claims that have been made about the health effects of daylight or other environmental conditions, as reflected in absenteeism rates of building occupants.

4. These findings may have important implications for the design of schools and other buildings.

* These results, affirm that daylight has a *positive and highly significant* association with *improved student performance*.

Figure 52. Student Performance Based on an Increased Amount of Day Lighting

Due to complexity concerns the analysis of these findings was hard to document, but they do give a reasonable outlook for the importance of proper window selection in school buildings.

Alternative Window Selection

By acknowledging the benefits of energy-efficient windows I can actively participate in analyzing how cost effective they may be when compared to a traditional window selection. Currently, Efficient Windows Collaborative (EWC) members have made a commitment to manufacture and promote energy-efficient windows (Efficient). Further commitments have been made by the International Code Council (ICC) by publishing the 2006 International Energy Conservation Code (IECC). The IECC is the national model energy standard certified by the U.S. Department of Energy pursuant to the Energy Policy Act (EPAct). EPAct requires that all states review and consider adopting the IECC as the state building energy code.

IECC CLIMATE ZONE 5			
Adams	Columbia	Lackawanna	Pike
Allegheny	Crawford	Lancaster	Schuylkill
Armstrong	Cumberland	Lawrence	Snyder
Beaver	Dauphin	Lebanon	Somerset
Bedford	Erie	Lehigh	Sullivan
Berks	Fayette	Luzerne	Union
Blair	Forest	Lycoming	Venango
Bradford	Franklin	Mercer	Warren
Butler	Fulton	Mifflin	Washington
Cambria	Greene	Monroe	Westmoreland
Carbon	Huntingdon	Montour	Wyoming
Centre	Indiana	Northampton	
Clarion	Jefferson	Northumberland	
Clinton	Juniata	Perry	

Figure 54. IECC County Selection (Pennsylvania)
Source: IECC

I used the IECC requirements for my window selection because I felt they best illustrated the principles of my selection criteria. To do this I first determined the county in which Baldwin high school resides. I used Allegheny county PA. as the initial basis for determining which IECC climate zone construction would take place in (see Figure 54.). I then used the table illustrated by (Figure 55) to determine other window performance requirements.

Package	Window & Door U-factor	Skylight U-Factor	Window, Door & Skylight SHGC
Climate Zone 4	0.40	0.60	NR
Climate Zone 5	0.35	0.60	NR
Climate Zone 6	0.35	0.60	NR

Figure 55. Windows Req. for Climate Zone 5
Source: IECC

I then selected windows

based on the weighted average U-factor and SHGC values which were less than or equal to the values of climate zone 5. I did this to meet the code maximum air leakage requirements. Because the actual estimate used for Baldwin inquired double glazed windows with an aluminum frame, I also adopted these characteristics into my selection criteria.

I decided to select a Double-Glazed with Moderate-Solar-Gain Low-E Glass, Argon/Krypton Gas composite window (see Figure 56.)

Figure 56, illustrates the characteristics of a typical double-glazed window with a moderate solar gain Low-E glass and argon/krypton gas fill. These Low-E glass products are often referred to as sputtered (or soft-coat products) due to glass coating processes. Low solar gain or Low-E products reduce heat loss and let in a reasonable amount of solar gain. This criterion makes this selection suitable for climates with both heating and cooling concerns. I felt that this product was the perfect choice for an educational facility regarding these certain types of climate change.

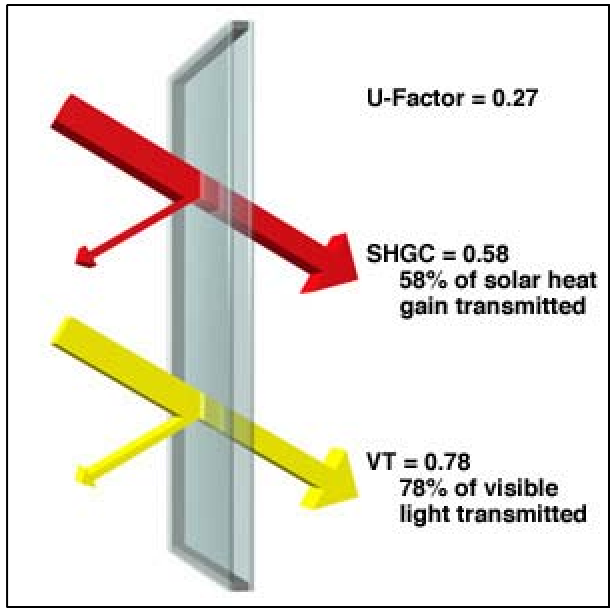

Figure 56. Double-Glazed with Moderate-Solar-Gain Low-E Glass Window Source: Efficient

Cost Comparison

In regard to the original selection of windows for Baldwin high school, the new Double Glazed Low-E windows actually provide more than environmental benefits to the project. Figures 57 and 58, demonstrate the SF cost comparison of the original selection of windows to that of the Low-E selection.

Alternative Window Comparison
Worksheet

Project Name: Baldwin High School
Dates of Construction: September 2005 - February 2006

Original (Double Glazed Window)	Qty (SF)	Unit	Price/SF	Total Cost
Traditional Double Glazed Window	3564	SF	$40.00	$142,560.00
			Total	$142,560.00
Alternative (Double Glazed Window)	**Qty**	**Unit**	**Price**	**Amount**
Double Glazed Window (Low E)	3,564.00	SF	$42.00	$149,680.00
			Total	$149,680.00

Figure 57. Total Window Costs

This cost comparison illustrates the acceptance of a better more environmentally friendly product when compared to that of the original window selection. The SF cost for both windows was relatively the same which provides reasoning behind only a 5% increase upon implementation of the alternate type of Low-E window.

CALCULATION (Alternative Window Selection)

Area of windows = 3564 ft^2

Original Window Cost (See Figure 57)

Total Cost = $142,560.00

Low-E Window Cost (See Figure 57)

Total Cost = $149,680.00

Increased Cost if Any
= (Low-E Window Cost) – (Original Window Cost)
= ($149,680.00) – ($142,560.00)
= $7,120

$7,120 = (Increased Cost)

5% = (Increased Cost %)

Figure 58. Alternative Window Selection vs. Original Window Selection

Conclusion

The purpose of this secondary analysis was to rectify the assumption that applying "green" building products into construction does not always indicate a drastic higher cost. My findings determined that you can successfully purchase a traditional estimated bid item for roughly the same cost as a more environmentally respectable selection. My cost analysis demonstrated that the selection of a Low-E, more sustainable window, only surmounted a 5% increase in cost (See Figure 58). Regarding the benefits that this type of window may suggest; for student learning and performance, this 5% increase seems somewhat minuscule. By researching for more energy efficient products, we as an economy can all benefit collectively. Depending on which manufacturer or supplier you choose, these benefits do not have to be dismissed due to increased cost concerns.

Acknowledgments

It is appropriate to acknowledge the contributions of those who aided in the compostion of my thesis report. More specifically, the cooperation of CEO and President of HHSDR Architects and Engineers, Greer Hayden was of much success to attaining all relevant building related information. The cooperation of The Pennsylvania State University staff and administration also aided with information imperative to successful completion of my senior thesis project. I would like to thank advisors Dr. David Riley and Mr. Kevin Parfitt for their continual assistance regarding thesis uncertainties.

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